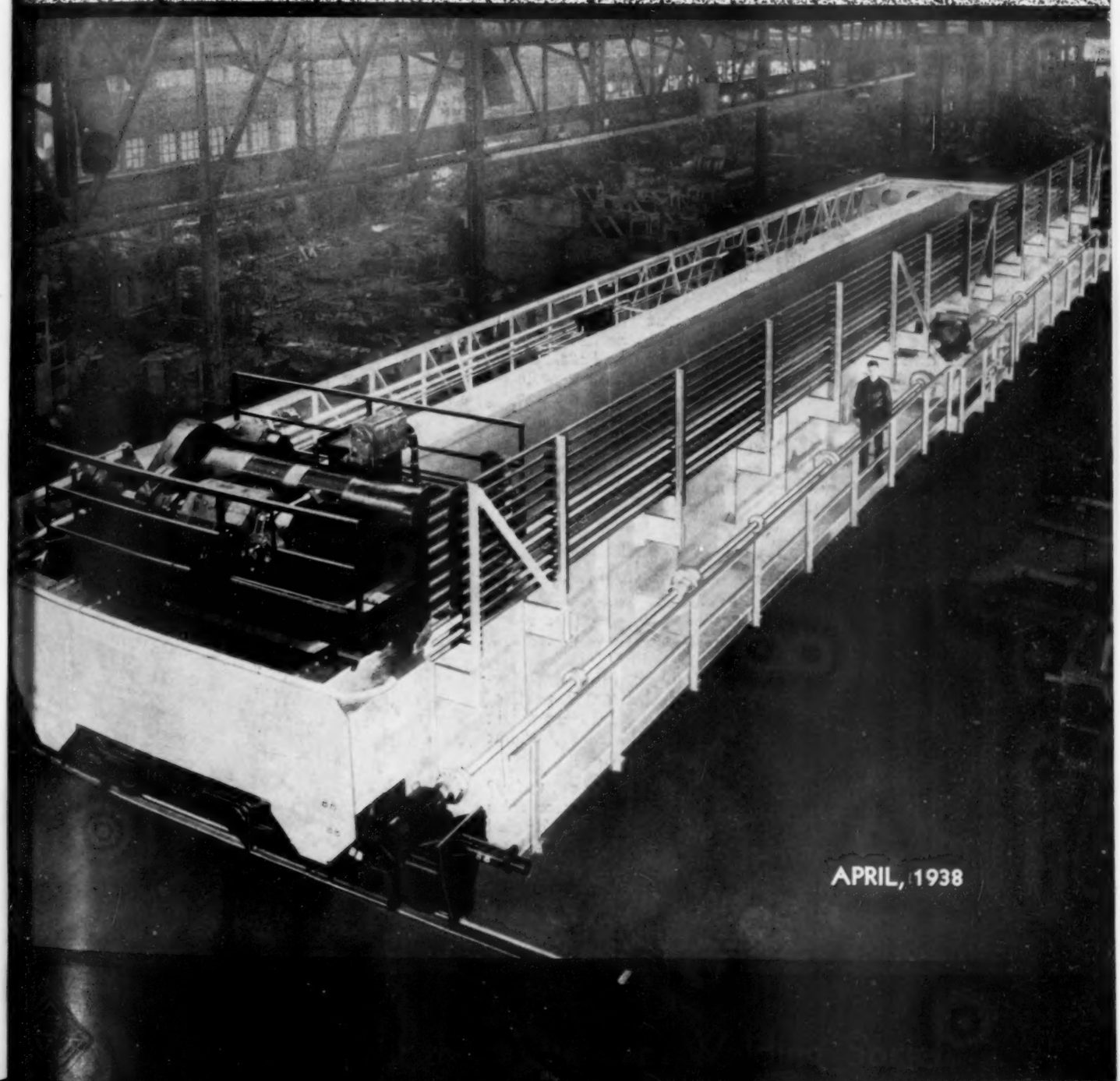
The Welding Journal



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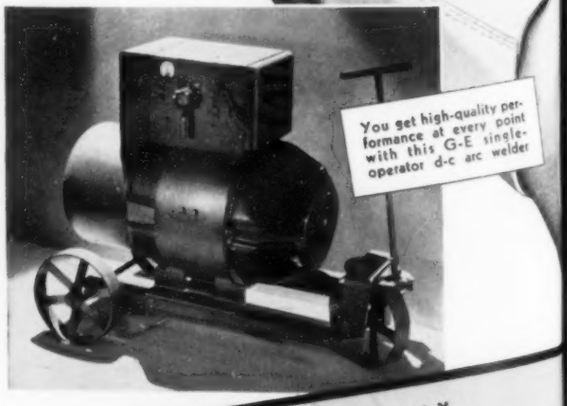

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Published for the Advancement of the Science and Art of Welding

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Volume 17 Number 4

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WORLD'S LARGEST SPAN ALL-WELDED CRANE

See Page 23 for Description

ISSUED MONTHLY

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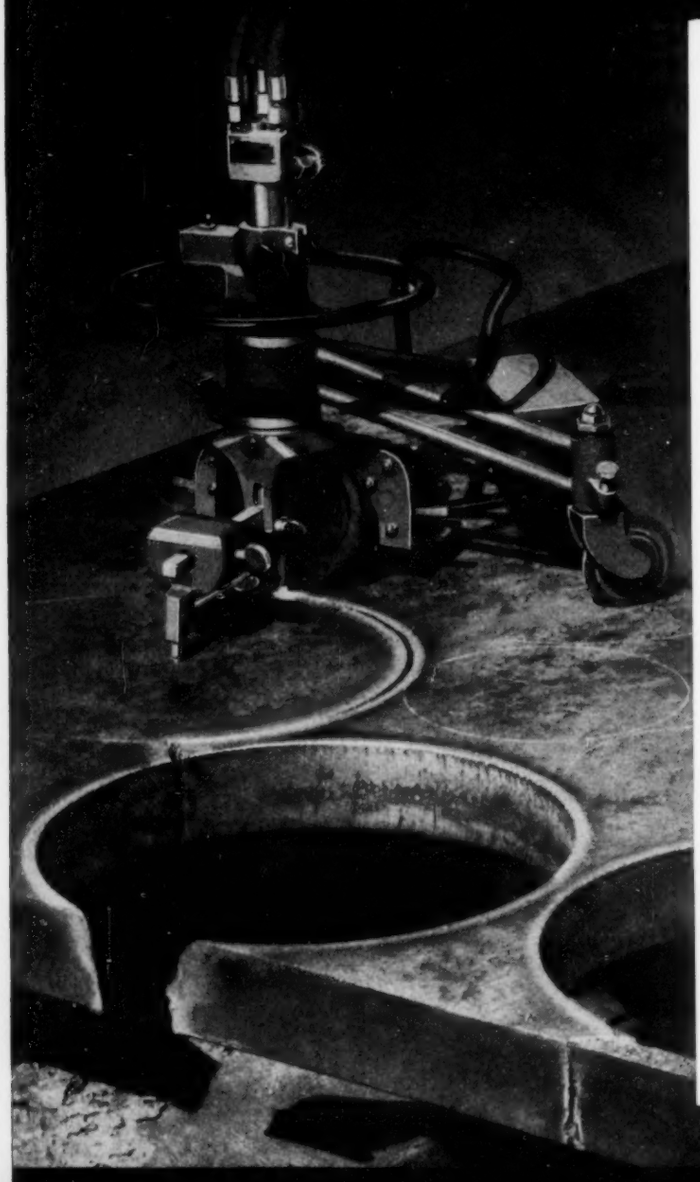

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Welding Journal

VOLUME 17, No. 4 APRIL 1938

Use of Welding in Structural Steel*

By C. E. LOOS†

DURING the past twelve years it has been interesting to observe the various trends in the development of welding in the structural steel industry. Previous to that time, and as early as 1908, electric arc welding was carried on in our shops with but little thought of its real possibilities as a means for making a stress carrying joint.

It remained for organizations directly interested in the promotion of sales of gas, electric power and welding equipment to pioneer in the building of completely welded structures. This welding was done without too much consideration of cost, for the average fabricating shop was not at that time any too well equipped or experienced in welding.

EARLY ALL-WELDED STRUCTURES

It was our privilege in 1926 to fabricate a five story all-welded factory building for the Westinghouse Electric & Manufacturing Company and a short time later several welded structures for the General Electric Company. It was our good fortune during that same period to gain experience in fabricating an all gas-welded mill type building for the Union Carbide Company at Niagara Falls. In those early days we also fabricated and erected an eleven story all-welded addition to the Homestead Hotel at Hot Springs, Virginia. While there was a distinct advantage to the owners in erecting the hotel addition by this noiseless method, I do not believe that any of the all-welded buildings fabricated and erected at that time were found to cost less than a riveted structure of similar type in spite of the saving in weight.

The use of the all-welded building did not progress as fast as was anticipated because of building code restrictions, fabricating difficulties, erection problems and general unfamiliarity and skepticism of the designing engineers.

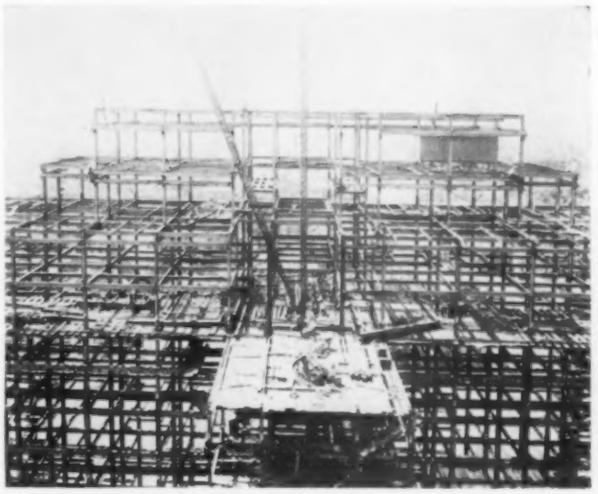

Fig. 2—du Pont Office Building, Wilmington, Del., 1936

This office building and connecting bridge was built for the du Pont Company at Wilmington, Del. It was a shop riveted, field welded and bolted job. The new building was located adjacent to an existing office building and it was essential that erection noises be reduced to a minimum. Fiber gears were required on hoisting equipment and motor generator welding sets instead of the usual gasoline engine driven units. You will note the welders at work near the top of the structure.

PRESENT DEVELOPMENTS

As the average structural shop became better organized and equipped for welding, rapid progress was made in its adoption for light structures, but in competition with riveted construction for large and complicated bridges and buildings, the engineer and fabricator were faced with problems of design, preparation of material,

* Presented before the St. Louis Chapter, AMERICAN WELDING SOCIETY, St. Louis, Mo., January 14, 1938.

† American Bridge Company.

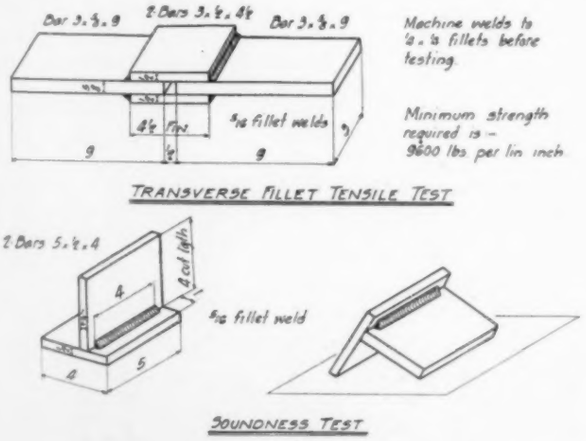

Fig. 1—Welders' Qualification Tests

The qualification of welders is very important in maintaining a high standard of workmanship. The upper test specimen shown here is one that we have used in some form over a period of years. Slight changes have been made from time to time as experience has dictated. The specimen is assembled in a jig and tack welded on the edges. These tacks are removed by chipping after the test welds have been made. You will note that $^{5}/_{16}$-inch fillet welds are specified and these are machined to $^{1}/_{4}$-inch fillets. This places every welder on an equal footing as to bead size and what is more important it emphasizes the value of proper root penetration. It is an inexpensive test specimen and is easily machined with paired milling cutters. The passing requirement is 9600 pounds per linear inch or 54,000 psi.

The soundness test specimen shown below is one that is frequently used as a preliminary test. A visual inspection of the broken weld will quickly reveal all of its defects.

Fig. 3—Welded G. E. Truss

These two welded girders for the General Electric Company's power house at Schenectady are used to support mercury boilers.
The sizes of the members and design loads indicated on the photograph.

assembly, distortion, shrinkage and other difficulties peculiar to welding that have usually made the completely welded structure more costly than a riveted one. It was originally believed that much of the material could be shipped directly from the mill to the bridge or building site and erected, but this practice has not been followed to any great extent on heavy work.

As we look about our shops at the present time we find that the rapid growth in volume of welding in the bridge and building field has not been in the all-welded type of structure, but rather in the welding of members that are part of a riveted structure. We may find in time as our knowledge of welding and its possibilities increases, that the use of welding will be extended to embrace many more structures in their entirety.

At present in the fabrication of riveted bridges we are welding, when permitted, such items as shoes, hand railing and posts, end dams, expansion grating, floors, facia girders, curbs, roadway gates, catch basins, downspouts and blast plates. The design of these items varies considerably with the type of bridge and the individual preferences of the designing engineers.

Welding plays an important rôle in the reinforcing and strengthening of old bridges. One of the early jobs of this sort was the reinforcing of the Missouri River Bridge for the Chicago, Great Western Railway Company at Leavenworth, Kansas in 1927. When used in this capacity welding serves as a very economical means for attaching new parts to the existing structure, thereby often saving costly drilling of holes and removal of old rivets.

The use of the steel grid or grating floor for old as well as new bridges has developed rapidly in the past few years, since it has become possible to connect such material to the structure by welding. A most notable example of this type of construction was the flooring of a bridge for the Bessemer & Lake Erie R. R. crossing the Allegheny River at Cheswick, Pa. The bridge deck had been damaged several times by fires and watchmen were required to be on duty at all times. With the welded steel flooring the track was laid in ballast. The fire hazard has been eliminated and track maintenance is taken care of by the regular track gang.

On some riveted buildings we are welding details, such as grillages, column bases, ladders, stairs, gutters, downspouts, louvers, doors and door frames. It should be noted here that not all of the aforementioned items applying to bridges and buildings are welded, because the fabricator very often has no choice in the matter of whether a part is to be welded or riveted. However, such parts of structures that are now welded require the services of over a hundred welders in our shops.

Fig. 5—Welded Truss for Rancocas Creek Bridge, N. J.

The Riverside-Delanco highway bridge crossing Rancocas Creek, Burlington County, N. J., is made up of three all-welded pony truss spans. The trusses here illustrated are built up almost entirely of Carnegie beam sections 14 inches in depth. Note the bend in the upper gusset plates. This was necessary to take care of the overrun in depth of the diagonal members.

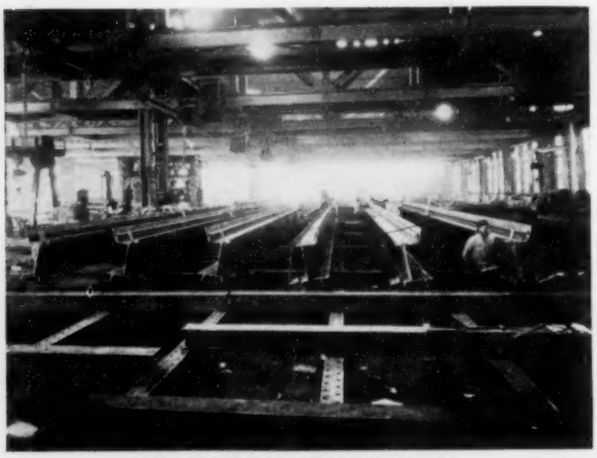

Fig. 4—Mill Building Gutters—Irvin Mill

These are welded gutters for the new Carnegie-Illinois Irvin Mill. They are here shown on the welding skids and are turned up on their sides. They are made up of plates welded between two channels and serve also as eave struts. Note the weld bead on the back of the channels. This bead serves to straighten the member after it has been welded.

When parts of a riveted structure are welded, they should be welded, as far as possible, in their entirety. Rivets and welds should not be called upon to share the load on a joint because they will not function properly together. There are times when both methods of joining parts in the same member may be employed to advantage, but if any holes are punched in a member and rivets driven, the cost of the additional work to make a completely riveted member may be relatively small. Extra handling of the material is avoided by using but one joining process for a single member.

WELD ENGINEERING

Our engineering costs have been greater for welding because standard forms of connections have not been developed to the same degree as for riveting and the joint details must be carefully analyzed. It is necessary also to prepare sketches of connections for field use. This is not the general practice for riveted work.

In bridge and building work much depends upon the ability of the designer. Since welding is a comparatively new method of construction, the designer may not have acquired the necessary experience and this often results in improper applications and high costs. A structural designer, who is not well informed in welding practice, may follow blindly designs appearing in publications without taking the trouble to ascertain whether

Fig. 6—View of Bridge Floor B. & L. E. R. R.

This view shows the T-Tri-Lok Bridge floor welded in place on one-half of the 3000 feet B. & L. E. R. R. Bridge. Traffic was maintained without interruption while the new floor was installed. Note the timber construction on the right.

they are sound, practical or economical. For example, in the old bare wire days the $^3/_8$-inch fillet was considered standard and was figured to take a working stress of 3000 pounds per linear inch. Today with the use of the heavily coated electrodes, which give a weld of 25 per cent greater strength and much better ductility, we find many engineers still copying old specifications and requiring the $^3/_8$-inch fillet for a load of 3000 pounds per linear inch when he could now use more economically a $^5/_{16}$-inch fillet which has greater strength and is about the maximum size for a good fast non-positioned one pass fillet weld. He is also found guilty of using beam to column connections computed for direct shear only, without giving consideration to the moment set up by the deflection of the beam if its end is restrained. A great deal has been published on welded beam to column connections and many of the proposed schemes have been found entirely inadequate when analyzed by our engineers. We are using for such connections the design data prepared by Mr. H. M. Priest and published in THE WELDING JOURNAL of August 1933.

Unlike many other industries in which welding is employed, the structural engineer is often not associated directly with the fabricating shop. He may, therefore, not be fully acquainted with shop and field practices. He cannot always appreciate the practical fabricating problems and may design according to theory only. It is in such cases that we find, for example, the splicing of plates of different thicknesses in girder flanges to save weight, when the extra cost of material, if a single thickness were used, would be less than the added shop costs for the lighter girder. We find, also, that small fillet welds, which may be ample from the theoretical standpoint, are specified for welding thick plates when we know that such welds will sometimes crack because of the quench effect due to the rapid dissipation of heat. We have set up certain minimum permissible fillet sizes for various thicknesses of material to avoid the possibility of having cracked or highly stressed welds. One of the factors directly related to the cost of welded construction is over-design and excess welding in general. Unit stresses with large factors of safety have been quite well established from the results of numerous tests, yet there is a tendency for the designer to play safe and add more welding. His drawings go to the shop and the welder, to be on the safe side, adds a little more, while the inspector may go a step farther and insist upon a reinforced weld. Excess welding may also increase the warpage and thus add to the straightening costs.

It is very important that the drawings for welded construction convey to the shop and erector all of the necessary information essential for properly welding the member. Where special precautions in welding sequence, types of electrodes, preheating or other unusual

Fig. 8—All-Welded Barge—Standard Oil Co.

This is a view of an all-welded oil barge under construction. It is 26 feet wide, 145 feet long and 7 feet 7 inches deep and has eight separate oil storage compartments

procedures are required, this should be included on the drawings. Too often procedures are discussed in the designing department, but the results of such discussions do not reach the welder. At this stage in the development of welding the designer should at times consult the fabricator or erector as to the most economical way of making a joint and when the decision has been reached, the information on the drawing should be made specific. It often will be found that a few simple tests of special joints can be of considerable assistance when making decisions involving large duplication or unusual strength requirements.

QUALIFICATION AND INSPECTION

It is here assumed that the fabricator employs only qualified welders who work under proper supervision. The fabricator cannot afford to do otherwise. The necessity for properly qualifying welders has been quite apparent from the start, but it is a matter that is sometimes overdone. The fabricator is often called upon to re-qualify his welders for each and every customer in accordance with the customer's particular specifications Some of these tests are costly and some so lenient that they are not worth the trouble and cost of preparing the specimens. We prefer to use a fillet weld break test, supplemented by a simple transverse fillet weld tensile test.

There should be competent inspection of welds both during and after welding. The X-ray or Gamma ray

Fig. 7—Welded Bridge Floor—Homestead High Level Bridge

The new Homestead, Pa., High Level Highway Bridge on which Carnegie I-Beam-Lok welded flooring has been used.

methods have not been used to any great extent, if at all, for the inspection of welds in bridge and building work.

FABRICATION

One of the greatest difficulties encountered in certain types of welded bridge and building construction is the overrun and irregularities in rolled steel sections. These uncertain quantities, with which the fabricator and erector must deal, are easily taken care of in riveted construction by the use of bolts, drift pins and shims, but the welder cannot resort to such measures for he must make his assembly with surfaces in contact and usually with no holes in the joint. The use of shims is not generally recommended in the welded joint. Many authorities have discussed the necessity for developing new structural shapes to meet the demands of welded construction, but it is my opinion that structural welding can best be served at the present time with smaller mill tolerances on the existing shapes. This may entail extras and increase the cost of the structural steel.

Fig. 9—Main Control Shaft—Fort Peck Dam

This view shows the complete assembly of two rings or twelve segments of a control shaft of the Fort Peck Dam. These shafts were 54 feet in diameter. Angles for field erection were welded along the four beveled edges of the segmental plates which ranged from $^{5}/_{8}$ to $1^{1}/_{8}$ inch in thickness. When assembled the plates were joined in the field with a single V butt weld.
(528 Pcs. 8 ft. 4 inch x 28 ft. 0 inch—2400 tons—30,000 lin. ft. $^{5}/_{8}$-inch welds.)
(Angles 4 x 4 x $^{1}/_{2}$ inch.)

There are usually few, if any, holes in parts for welded construction. This saving is partially, and sometimes entirely, offset by the added costs of assembly and by the extra care required in the preparation of the edges or the ends of the material in order to insure proper fit-up.

Assembly plays an important rôle in welded structural steel fabrication and may add considerably to its cost. It is usually found to be more profitable to spend extra time on the preparation and assembly of the material than to have poor fit-up which necessitates an extra amount of welding. Where there are many duplicate pieces the use of jigs is, of course, the only economical method of assembly, but much depends upon the ability of the fitter. He must arrange for suitable jigs and clamping devices and see that the work is properly tack welded. When working points are outside of the member his difficulties are increased. A welding fitter should have had previous experience as a layerout.

In welded construction warpage and shrinkage are problems that must be given due consideration on every job and preventative measures should begin in the designing department. A large amount of warpage can be and is prevented by the skill and experience of the fabricator. That which remains in the completely welded member may be removed by the application of localized heat or by mechanical means. Straightening by either method adds considerably to shop costs.

Fig. 10—Catamount Creek Dam Near Edlowe, Colo.

The surface of this earth fill dam for the storage of water on the north slope of Pike's Peak for Colorado Springs was faced with steel plates welded into one piece. This project is described in the *Engineering News Record*, Oct. 29, 1936.

As for the controversial subject of stress relieving, it is pretty much out of the picture in so far as it applies to bridge and building construction.

There is another matter to be considered in the development of welding in the structural steel industry, and one that also directly influences cost, and that is shop facilities. Welding at present requires a larger floor area, but less expensive and fewer pieces of fabricating equipment than for riveting. In the future we may find a more extensive use of manipulators, clamping devices, jigs and automatic welders with an equipment set-up that will rival our present riveting layouts. In bridge and building construction automatic welding equipment has not as yet been employed very extensively, principally because there is not sufficient duplication, or continuous welding, and the welded parts are often too bulky or irregular in shape.

ERECTION

One of the handicaps that the welding erector must face is the difficulty of making good welds in bad weather. His work may be halted or slowed up because of extreme cold, wind or wet steel. When it stops raining the riveters can go directly back to work, but the welders must wait until the steel dries. High winds that do not hamper the riveters make it difficult for the welders to control the arc. Some specifications prohibit welding in extremely cold weather. It is also essential that

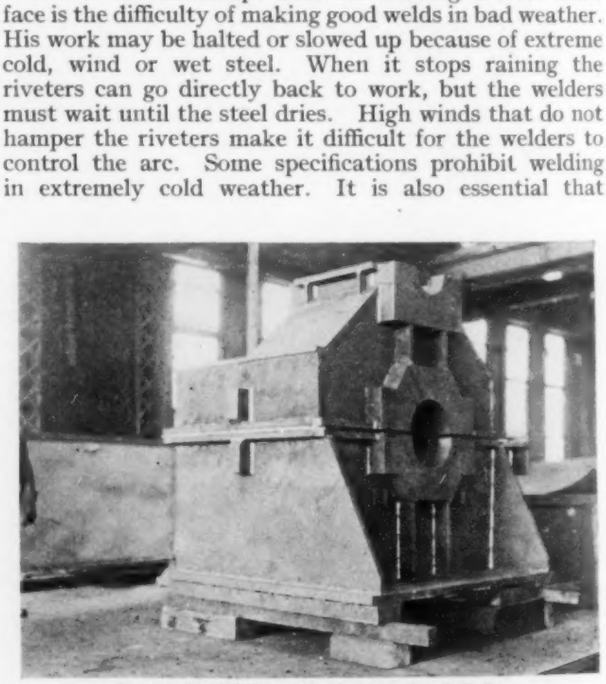

Fig. 11—Welded Housing for Coiler A. S. & T. P. Co.

This welded coiler housing built for the American Sheet & Tin Plate Division of the Carnegie-Illinois Steel Corp. is a good example of welding applied to machinery bases. Note that the fillet welds are not of uniform section. It was necessary for this housing to hold oil and a sealing bead was used throughout.

Fig. 12—Jig for Welding A Frames H-1096

This jig used for welding some six hundred A frames is mounted on trunnions so that welds on both sides may be made in the down position.

welds be made on a clean surface free from paint and that after welding the steel be thoroughly cleaned of slag and spatter before painting.

In welded construction the erector is often handicapped by the lack of holes which afford a convenient means for pulling the material together. Proper alignment must be made with a liberal use of guy lines. Parts such as large trusses, which cannot be shipped as a unit, are difficult for him to assemble and weld on a rough and oftentimes muddy site without reasonably level skids. It is, of course, important that such members be free from distortion.

WELDING ADVANTAGES

In spite of these obstacles that we are meeting in the development of welding in the heavy structural field, there are numerous advantages to be gained by welding. These include weight saving, noiseless erection, more pleasing appearance of the structure, sealing of joints against corrosion, rigidity where desired and many others.

FUTURE FOR STRUCTURAL WELDING

We are now rapidly reaching a point where welding will be recognized in the building codes of all of the major cities. I do not know to what extent the building code restrictions have retarded the development of welding in that field, but do believe that they have and that we will soon note an increase in the volume of field welded tier building work.

The completely welded bridge or building will be adopted only when welding becomes the most economical method of construction. This can be brought about only by the ingenuity of the designer, fabricator and erector and by the development of improved welding equipment or processes.

Welding offers a fertile field for originality in design and fabrication and we find that engineers best acquainted with the possibilities of welding are departing from conventional structural practices and are finding in welding the solution for many intricate joints. The shop likewise is developing through experience a new technique in the fabrication of welded products.

The flame cutting torch has played no small part in the advancement of welding. It has come to the assistance of the welding torch in the split beam arch, rigid frame and tree type of construction, so that structural members are gradually taking on a new form. It is in this type of development that one may expect to find greater uses of structural steel welding in future bridge and building construction.

Where rolled shapes could be used to replace castings, the fabricator was quick to take advantage of the welding process because it offered a considerable saving in the cost of material and produced a better product. For the more complicated shapes, castings are still used by welding them to rolled material.

There are certain structures formed largely with plates, such as tanks, pressure vessels, pipe lines, penstocks, barges and boat hulls, where the advantages of welded construction in tightness, corrosion resistance and weight reduction are so apparent that welding is usually specified even though the cost may be higher than for riveted construction.

When used in fabricating cranes, truck and railway car bodies and their frames, the reduction in dead weight is a factor which gives welding a decided advantage over riveted construction.

Welded low-alloy high-strength steels have played an important rôle in the building of transportation equipment, but they have not been used very extensively in our shops. The steel mills responsible for the development of such steels have been careful to keep the carbon content below $^1/_4$ per cent in order to insure weldability. The development of suitable welding electrodes has kept pace with the newer steels.

SUMMARY

In summarizing, it may be stated that for certain uses of structural steel, welding has a definite and economical advantage over riveting, while for other work, such as large bridges and buildings, its use must be confined to auxiliary parts until such a time as the complete structure can be economically fabricated and erected. We regard welding as a very useful and indespensible fabricating process and use it whenever it is profitable and permissible to do so.

The illustrations are intended to show some of the welded products fabricated by the American Bridge Company and to illustrate some of the problems encountered in structural welding. A few of these pictures have been published, but the majority are of comparatively recent origin. Unfortunately we neglected to photograph many of our more important welded structures and novel types of construction. The photographs, which I have selected are in no way spectacular.

Fig. 13—Welded Fixed and Expansion Bridge Shoes

The Welded Bridge shoe using rolled steel slabs offers a real advantage in strength and economy in replacing the often unreliable steel casting. Here are shown welded fixed and expansion bridge shoes. The $5^1/_2$ inch verticle slabs are welded to $2^1/_2$ inch and $3^1/_2$ inch horizontal slabs are braced by two wing plates.

THE METALLOGRAPHY OF WELDS*

By OTTO H. HENRY†

IN ORDER to intelligently interpret the revealed microstructure of any piece or section of iron or steel, whether welded or unwelded, it is necessary to understand the Iron—Iron Carbide Equilibrium Diagram and in order to understand thoroughly the Iron—Iron Carbide Equilibrium Diagram it is essential that one be able to visualize the mechanism of crystallization. It, therefore, seems logical that we should begin our discussion by familiarizing ourselves with the manner in which crystals themselves are built up. We are all inclined to visualize a crystal as something hard and brittle and possibly transparent, having in mind of course some of the materials with which we come in contact nearly every day, such as window glass and diamonds, etc. We are partially corrected in our assumption because diamonds are crystals but window glass is not crystalline—it is amorphous. Glass at room temperature is just a very viscous liquid. It is probably flowing now but we need have no fear of the panes flowing out of the windows of this room tonight because at room temperature the flow is very slow indeed. I wonder if there is any one in this room who knows the melting temperature of glass? The answer is quite difficult because it has no definite melting temperature—it just becomes more and more liquid as it is heated, that is, it gradually softens with temperature rise and thus has an entirely different behavior in that respect from crystalline materials.

The next question confronting us is an understanding of the basic difference between an amorphous material such as glass and a crystalline material such as diamond or any of the metals or alloys because all metals and alloys are crystalline. The basic difference lies in the arrangement of the atoms of which the material in question is built up. The atoms in an amorphous material or a liquid are, in most cases, arranged in no definite order, that is, they are in a more or less scrambled condition while in the case of a crystal the atoms are arranged in a very definite order. The order of arrangement depends upon the metal or crystal in question because there are several ways in which the atoms arrange themselves. The most usual external form of metallic crystals is cubic. That is the atoms arrange themselves in repeating patterns in such a way as to result in the formation of a solid with a definite geometrical outline such as a cube. Iron and steel in which we are possibly most interested crystallizes in the cubic form.

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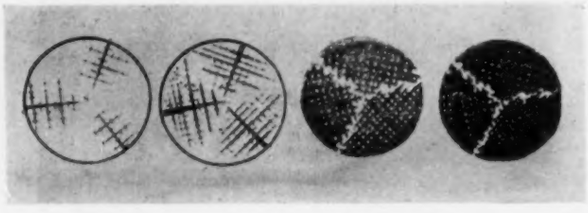


Fig. 1—Diagram Representing the Growth of Three Separate Crystals. Stead

EQUILIBRIUM DIAGRAM FOR STEEL (IRON AND IRON CARBIDE)

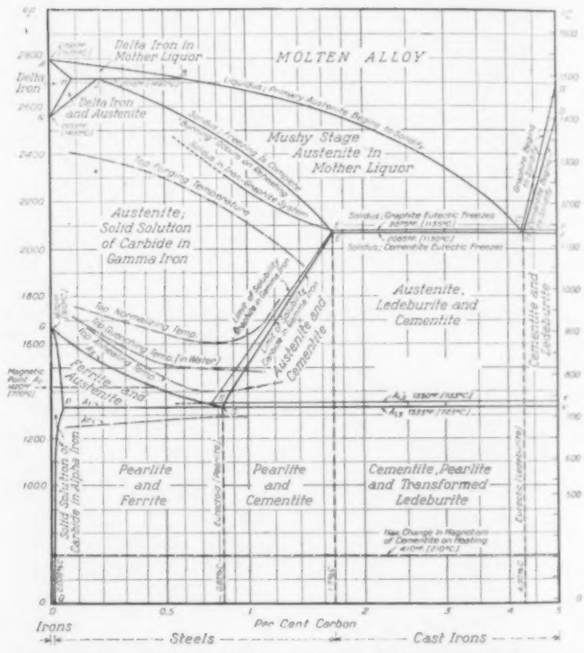


Fig. 2—The Iron-Iron Carbide Equilibrium Diagram (Metal Progress)

Before proceeding further it may be advantageous for us to spend a few minutes on the atoms themselves because they are the material of which the crystals are built up. Needless to say, they are very small, so small that there are approximately 100,000,000 of them per linear inch in the metal tungsten. To get an idea of their size we might consider enlarging the individual atoms in a cubic inch of tungsten to a sphere with a diameter of $^1/_{100}$ of an inch, which is about the smallest size one can comfortably see with the unaided eye. If this could be done the cubic inch with which we started would now assume the proportions of a cube approximately 15 miles on a side or have a volume of 3375 cubic miles.

The atom or the sphere of influence of the atom of which we have been speaking is not solid in any sense of the word but is in turn made up of two or more entities. The two main components are possibly the nucleus which carries a positive charge and a sufficient number of negatively charged electrons to balance electrically the charge on the nucleus. Many other components of the atom, such as the neutron, deutron, positron, etc., have been described by different scientists comparatively recently. We may, for ease of comprehension, compare the make-up of the atom to our solar

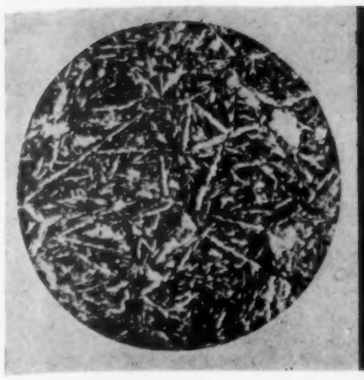


Fig. 3—A Photomicrograph of Steel Containing 1.50% Carbon Which Has Been Cooled Rapidly from Above the Critical Range. The Structure Is Martensite

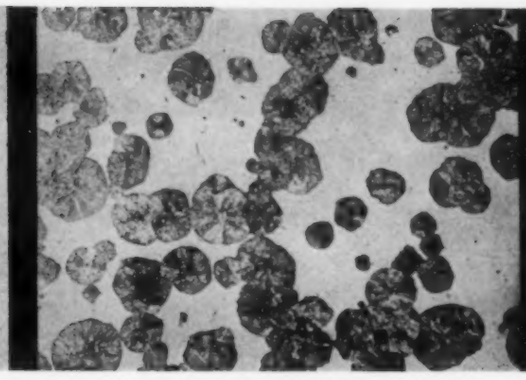


Fig. 4—1.50% Carbon Steel Cooled Rapidly from Above the Critical Range and Then Reheated to About 250° C. The Black Nodules Are Troostite—the White Matrix Is Martensite

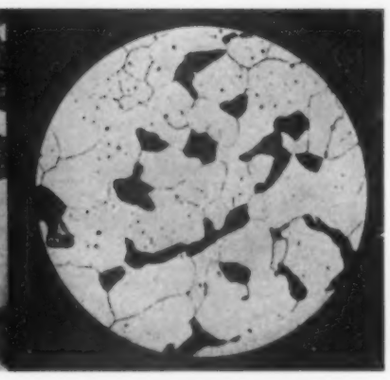


Fig. 5—Annealed 0.10% Carbon Steel. Black Areas Are Pearlite. White Grains Are Ferrite

system. Let us assume that the positive nucleus of the atom is the Sun of our solar system and that the different planets, such as Earth, are the electrons—then the proportional sizes and distances are comparable. Thus, we see that an atom is actually composed of very little matter and a great deal of space or void. The element hydrogen has a single positive charge on the nucleus and one electron—the other elements have higher and higher positive charges on the nucleus and a sufficient number of negatively charged electrons to balance the nucleus electrically.

These atoms, of course, play a very important part in metals and alloys because, whenever a metal or alloy changes from the liquid to the solid state, that change is accompanied by crystallization. That is, the atoms arrange themselves in such an order of repeating patterns in three dimensions that the result is the formation of a solid with some definite geometrical outline.

We are all more or less familiar with the term "grains" because we talk about the coarse grain or fine grain fracture of a weld but so far tonight we have talked only of crystals. As a matter of fact, grains are crystals. Crystals may be idiomorphic or allotriomorphic. The arrangement of the atoms within the crystal may be the same in either case but the external form is different—idiomorphic crystals have a perfect external form while the allotriomorphic crystals have assumed the shape of the surroundings. The proper name for the crystals in a metal or an alloy is "allotriomorphic crystalline grains" but we usually delete the first two descriptive adjectives and say "grains."

The sketch shown in Fig. 1, according to Stead, an eminent metallographist, diagrammatically depicts the formation of three adjacent grains as they crystallize from the liquid. Crystallization progresses from some point and the atoms build on in three dimensions until collision occurs with some adjacent grain growth. The line of collision will determine the grain outline and the frequency of the points about which crystallization begins will determine the size of the final grains.

Since the original formation of the grains takes place during primary crystallization it will be expedient for us to turn to the Iron—Iron Carbide Equilibrium Diagram Fig. 2. and see just where they form in relation to it. The topmost line on the diagram is called the liquidus line because everything above it is liquid and the next line below it is called the solidus because everything below it is solid. Between these two lines there is a mixture of liquid and solid in a state of equilibrium. The more slowly the melt is cooled from the liquidus to the solidus the larger will the resultant grains become and, of course, the more rapid the rate of cooling the smaller will be the resultant grains. Thus in a heavy weld pad there will be more weld-metal, the base metal will contain more heat units, the cooling will be slower and the resultant grains will tend to be larger than in a thin weld.

After the metal has cooled below the solidus line it consists of a solid solution of carbon, in the form of the chemical compound Fe_3C, in gamma iron. This solid solution is called Austenite and is non-magnetic.

The meaning of the term "solid solution" is rather difficult for many of us to understand because we cannot even visualize the possibility of dissolving a solid in a solid, yet that is exactly what happens when a piece of

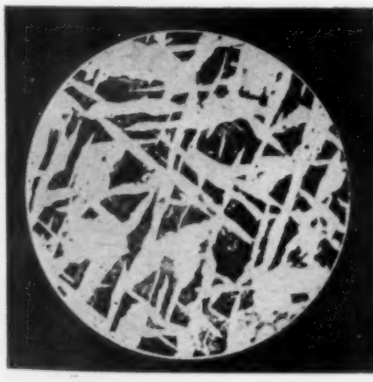


Fig. 6—Cast Steel Containing About 0.30% Carbon. Black Areas Are Pearlite. White Areas Are Ferrite

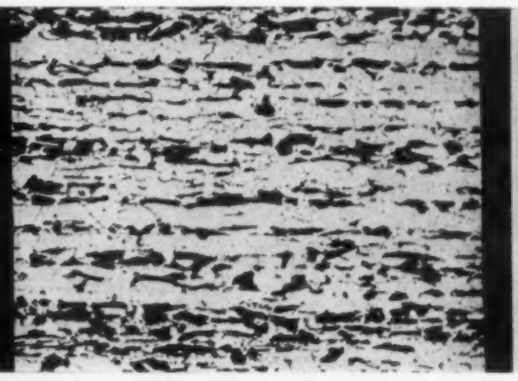


Fig. 7—Longitudinal Section of Steel Containing About 0.30% Carbon. Note Bands of Pearlite and Ferrite Extending in Direction of Rolling

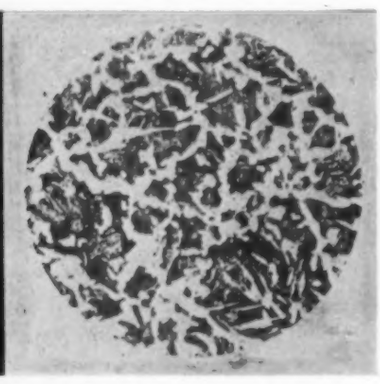
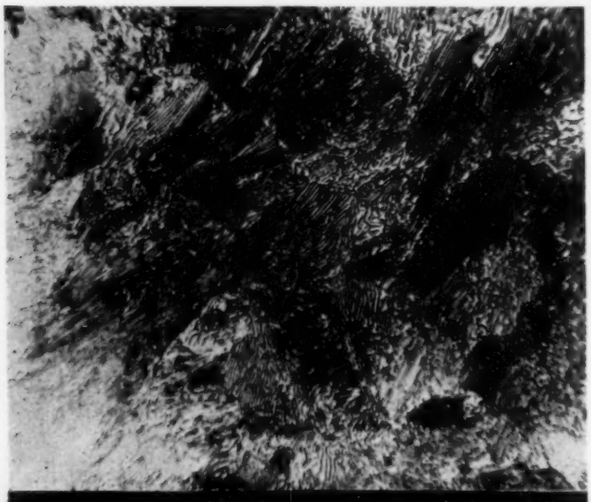


Fig. 8—Annealed 0.50% Carbon Steel

Fig. 9—Eutectoid Steel Containing About 0.85% Carbon. The Structure Is Entirely Pearlite



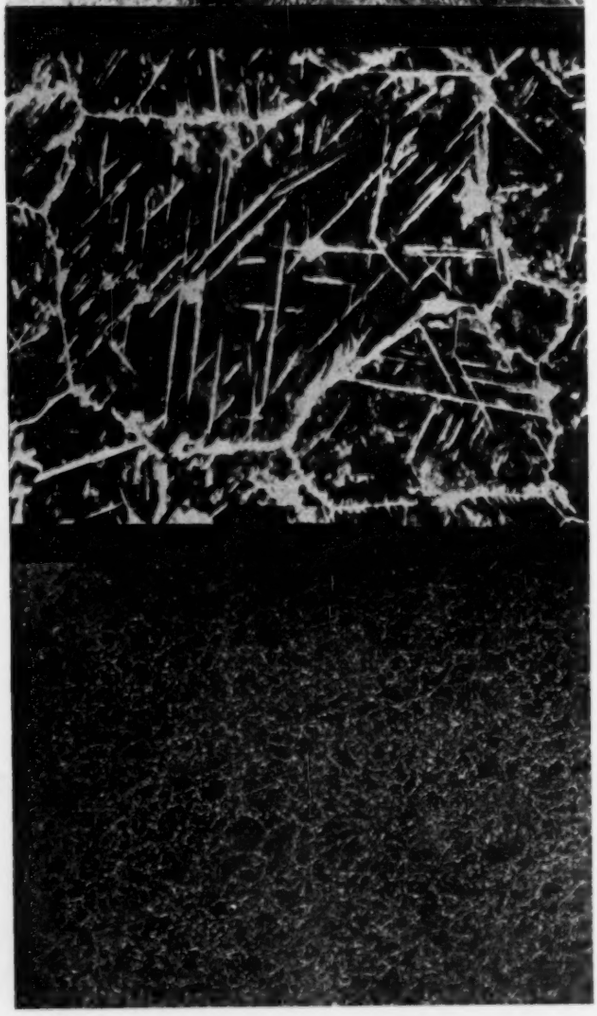


Fig. 10 (Center)—Cast Steel Containing About 1.40% Carbon. The Black Areas Are Pearlite and the White Areas Are Cementite

Fig. 11 (Bottom)—Annealed 1.40% Carbon Steel

iron or steel is case carburized—solid carbon is dissolved in solid iron. We all know that it is possible to dissolve a solid in a liquid because many of us practice it three or more times a day when we drop a few lumps of sugar in our cup of coffee and quite likely we practice dissolving a liquid in a liquid at the same sitting because many of us like to change the dark amber color of the coffee to a light brown by adding some cream. The rate of solution may be increasing materially in the case of solids in liquids or liquids in liquids both by stirring and by elevating the temperature, but in the case of dissolving solid carbon in solid iron the possibility of stirring is eliminated and temperature rise and possibly an increase in pressure are the only means at our command to increase the rate. The higher the temperature of the coffee or water, within certain limits, the more sugar will it dissolve—the same thing is true in the case of dissolving carbon in iron.

The atoms in the gamma iron are arranged in the face centered cubic form while the atoms in alpha iron which is stable below about 700° C. are arranged in the bodied centered form. In the face centered form there is an atom at each corner of the cube and one in the center of each face of the cube while in the body centered form there is an atom at each corner of the cube and one in the center. Alpha or body centered iron is capable of dissolving little or no carbon, while gamma iron is capable of dissolving carbon in the amount shown on the equilibrium diagram by the A_{cm} line. The amount varies with the temperature from about 0.85% carbon at 700° C. to 1.7% carbon, by weight, at 1130° C. When solid carbon dissolves in solid gamma iron a carbon atom replaces an iron atom in the space lattice in such a manner that there are always three iron atoms grouped about each carbon atom. In other words, the carbon, as such, does not dissolve in the gamma iron but dissolves in the form of a chemical compound, Fe_3C, which is called "iron carbide" or "cementite."

The cementite will remain in solution in the gamma iron until it becomes saturated or until the alloy is cooled to a temperature sufficiently low to cause the gamma iron to change to alpha iron when, if the cooling rate is slow, the cemenite will be thrown out of solution in the form of fine lamellae sandwitched between iron lamellae to form a structure which under a microscope resembles a thumb print and is called "pearlite." There are about 25,000 of these alternate lamellae per linear inch in pearlite.

We may profitably spend a few minutes at this time on the metallographical constituents obtained in steel by varying the rate of cooling. First we must understand the constituents which are stable and in accordance with the equilibrium diagram. Above the critical range, that is, above the A_{c_3} line and below the solidus line the solid solution of cementite in gamma iron, which is called "austenite" is stable and below the critical range or the A_{r_1} line the stable structure is "pearlite." Pearlite is formed when austenite is cooled slowly, as in a furnace, and cannot be formed by any tempering or drawing operation. The other metallographical constituents such as martensite, troostite and sorbite are not in a state of equilibrium—they have no place on the equilibrium diagram—they are transition constituents or steps in the change of the non-magnetic solid solution "austenite" to the magnetic mechanical mixture "pearlite." A photomicrograph of the structure called martensite is shown in Fig. 3. Martensite always exhibits a needle-like structure, it is the hardest and most brittle of all the metallographic constituents—it consists of alpha iron with particles of cementite possibly in molecular dispersion, along the cleavage planes,—it is the first stage of the change from austenite to pearlite, and is obtained by rapid cooling from above the critical range. If the cooling rate is not sufficiently rapid to produce a martensitic structure, troostite will be the result.

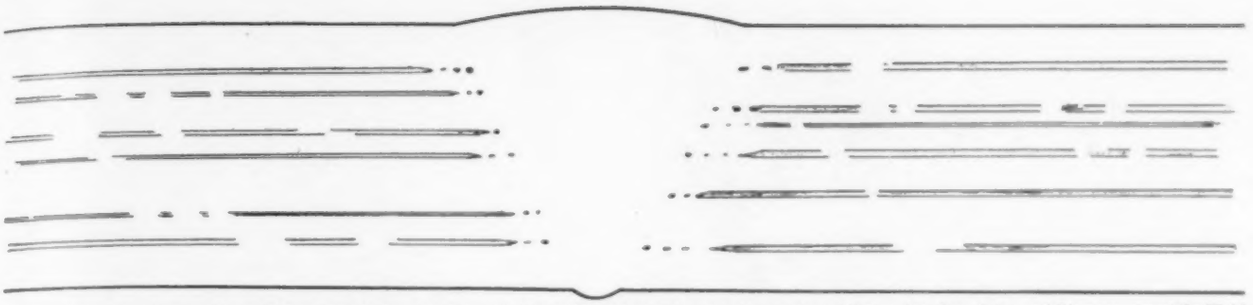


Fig. 12—Schematic Diagram of Deep-Etched Cross Section of a Fusion Weld in Mild Steel Plate Showing Segregation in Plate and Its Coagulation and Disappearance at the Weld

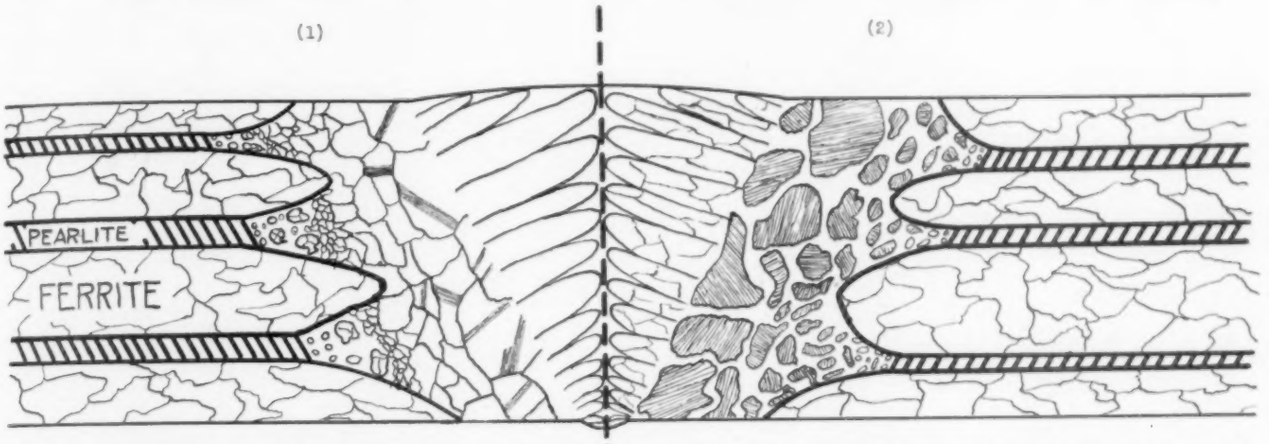


Fig. 13—Schematic Diagram of a Fusion Weld in Mild Steel Plate Showing Distribution of Ferrite, Pearlite and Zones of Different Grain Size at (1) at Time During Cooling at Which the Weld-Metal Has Just Frozen; (2) After the Entire Joint Has Cooled to Room Temperature

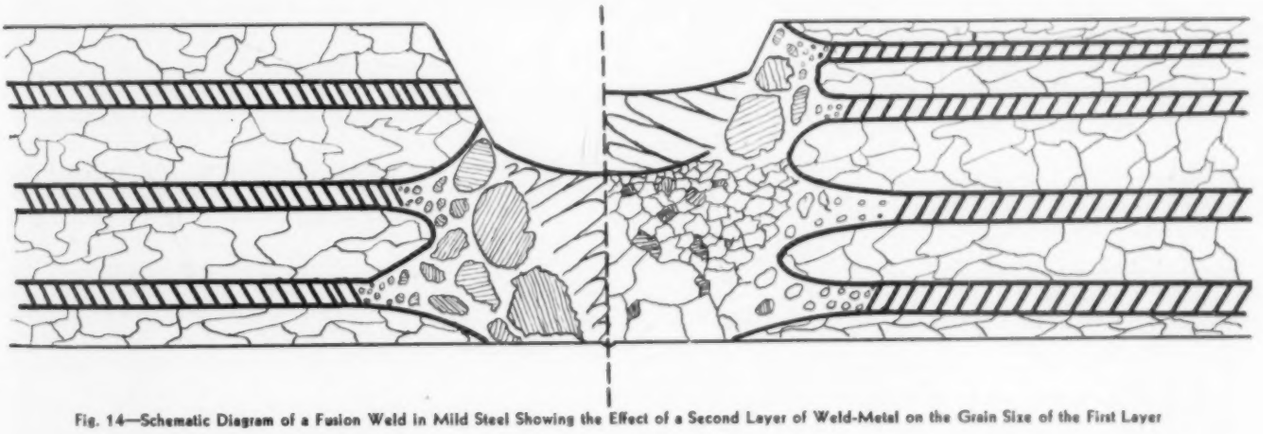


Fig. 14—Schematic Diagram of a Fusion Weld in Mild Steel Showing the Effect of a Second Layer of Weld-Metal on the Grain Size of the First Layer

The photomicrograph in Fig. 4. illustrates the appearance of "troostite". The black nodules are the troostite and the white matrix is martensite. It is the second stage of the breaking down of "austenite" into "pearlite" —it consists of alpha iron with an innumerable number of very small particles of cementite (larger than those in martensite) scattered throughout the mass—it dissolves in acids more rapidly than any of the other metallographical constituents and is much softer than martensite.

If the cooling rate from above the critical range is slower than that necessary to produce troostite but not sufficiently slow to produce pearlite—such as cooling small pieces in an air blast—the resultant structure will be "sorbite." Sorbite is a salt- and pepper-mixture of cementite and alpha iron. The cementite particles are much larger than those in martensite or troostite—they are sufficiently large to be seen under a microscope which is not possible in the case of martensite or troostite.

The question now arises as to just what causes martensite to be harder than the other constituents. Several years ago Dr. Zay Jeffries propounded the "Slip Interference Theory," which more nearly fulfills all the conditions than any theory advanced thus far. In order to understand this theory it is necessary to go back again to the arrangement of the atoms in a crystal. It has already been stated that the atoms arrange themselves in rows of repeating patterns in three dimensions. It can be seen readily that these multiple rows of atoms form planes of atoms which extend from one side of the crystal to the other. Also, whenever a crystal is stressed sufficiently to cause it to become permanently deformed, slip takes place between these planes of atoms. We might compare one set of these planes, which are

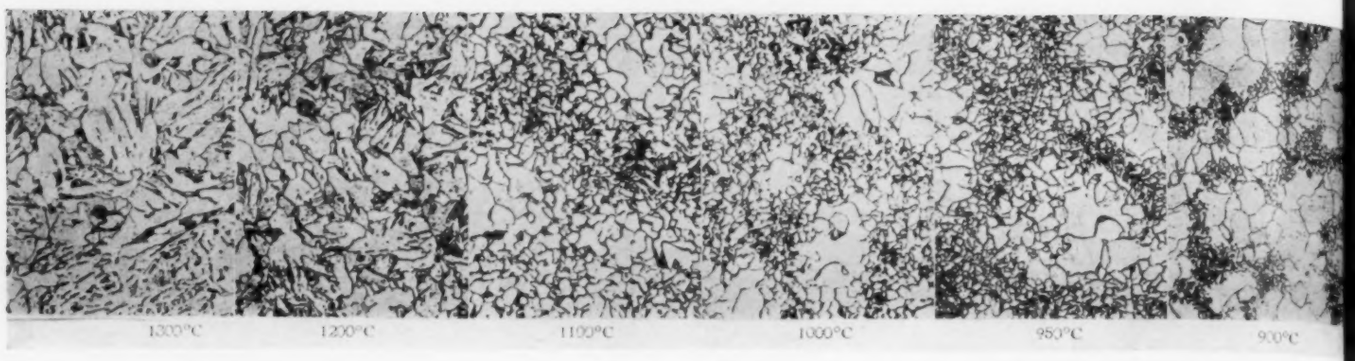


Fig. 15—Composite Photomicrograph Showing the Change

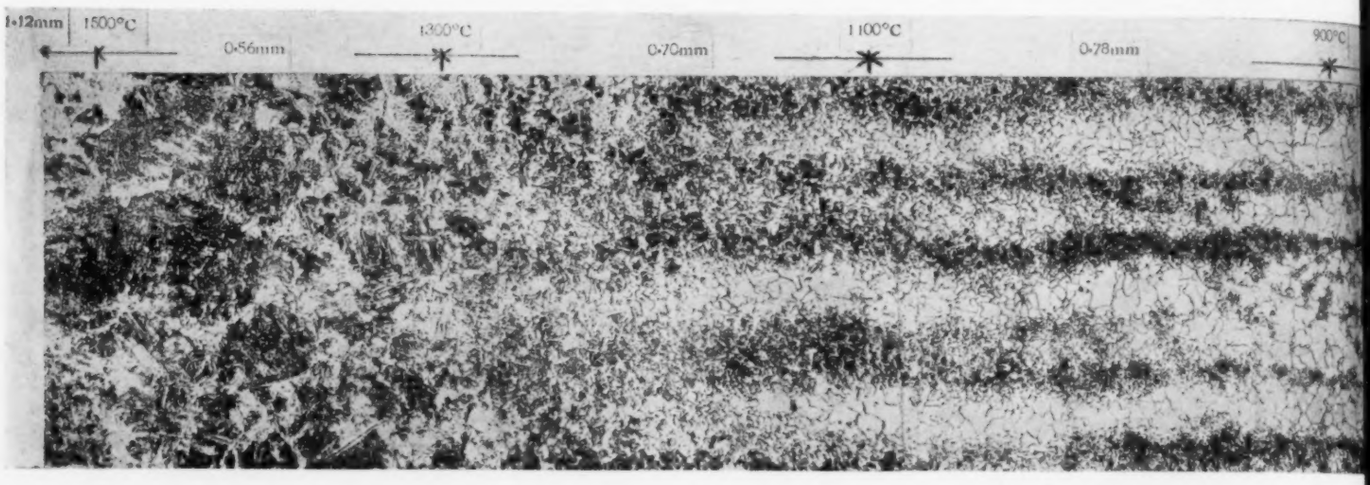


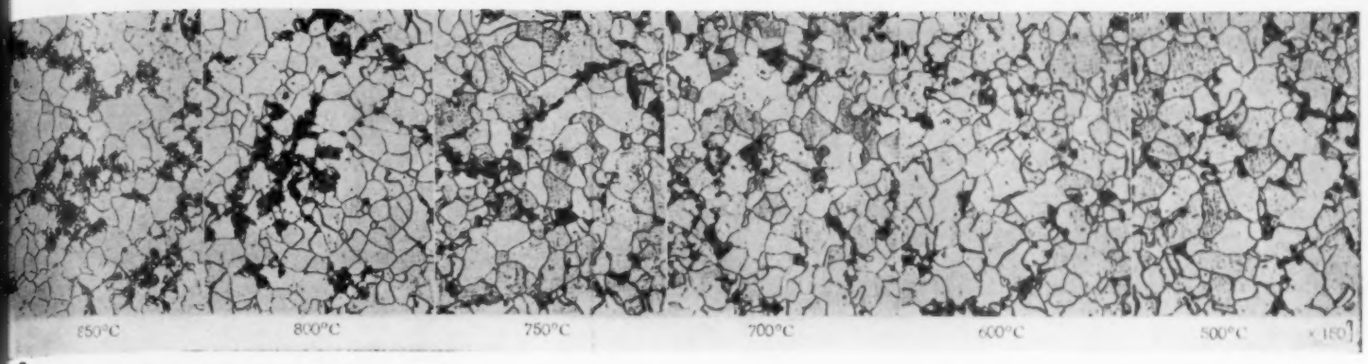
Fig. 16—Composite Photomicrograph Showing the Change

called "clevage planes," to the space between the cards in a deck and assume that the cards are the planes of atoms. If sufficient force is applied to a part of the stack of cards they will slip along each other and the deck will become elongated in the direction in which the force is applied. The same thing happens in a crystal. Now, suppose that we put some material between the cards which will impede their slipping, then, more force will be required to distort the deck. A street car motorman drops sand on the rails in order to prevent the wheels from skidding when he applys the brakes or wishes to accelerate on wet slippery tracks. In steel the cementite particles are thrown out of solution when austenite starts to change to pearlite and if it is cooled sufficiently rapidly to cause the steel to become so hard and rigid that the small particles cannot migrate and unite they will remain practically as molecules entrapped along the cleavage planes and prevent slippage in the same way as the sand prevents the car wheels from slipping on the tracks. The smaller the size of the cementite particles the greater will be their number and the harder will be the steel. As the rate of cooling is decreased the cementite molecules coalesce into larger particles and the steel becomes softer and softer until finally troostite is formed and then eventually when the particles become sufficiently large to be seen under the microscope the resultant structure is called "sorbite." An outstanding example of the properties of a sorbitic structure is evidenced in music wire. Rather small-diameter music wire is sufficiently ductile to be wrapped about itself but has a tensile strength of over 350,000 pounds per square inch with a carbon content of approximately 0.60%.

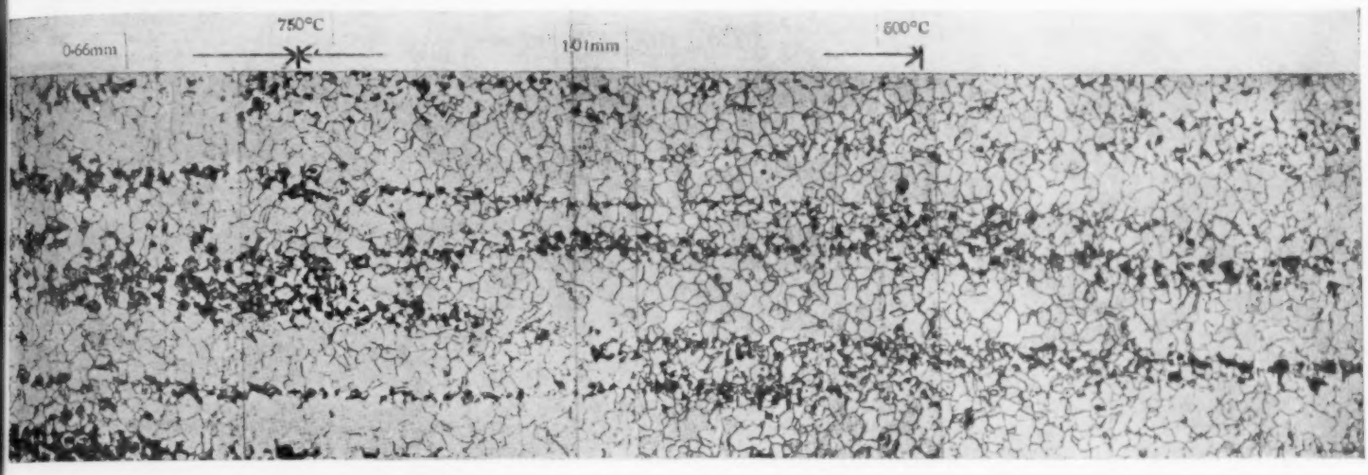
The fact must be kept in mind that austenite may contain a small percentage of carbon or it may contain a maximum of 1.70% carbon. It may be compared to sugar syrup because syrup may contain quite a high percentage of sugar or it may be very thin and watery, yet, it is still called syrup. Also, martensite may contain from a small percentage of carbon up to a maximum of about 1.70%. The hardness of martensite will, to an extent, depend upon the carbon content—the higher the carbon the harder and the more brittle the martensite. Martensite of a given carbon content will also vary in hardness depending on whether it is martensite which has just formed from austenite or whether it is martensite which is nearly ready to change to troostite.

It may be possible to get a better picture of just what is happening if we compare some of these metallographical constituents to the visable color spectrum. We all know that the color called "Blue" varies from indigo to green. There is a blue which is so nearly green that a dispute might easily arise as to which color it actually is—green or blue. Then again there is the color "green" which varies from blue to yellow. So it is with the metallographical constituents—there is really no sharp, distinct division line between them—each varies from one to the other. In many cases it would be almost impossible to say definitely whether the structure is trootite or sorbite, just as surely as one cannot tell definitely whether a color is green or blue, because the different metallographical constituents gradually change from one to the other. We should add an exception in the case of austenite because there is a distinct and basic difference between it and martensite.

We may possibly profit by looking at a few photomicrographs which depict the appearance of some annealed



Microstructure of the Plate Metal as It Approaches the Weld



Microstructure of Plate Metal as It Is Heated to Indicated Temperatures

steels with varying carbon contents. Figure 5 shows the transverse structure of a low carbon steel, containing about 0.10% C. which has been rolled down from the ignot to a rather small rod and annealed. The white crystals are ferrite or iron and the black areas or grains are pearlite. The magnification is not sufficiently large to show the lamellae in the pearlite. Pearlite contains about 0.85% carbon and each 0.10% carbon will produce about 12% of pearlite so that it does not take very much carbon to produce a large amount of pearlite. Pearlite contains a more nearly fixed percentage of carbon than any of the other metallographical constituents in steel, unless we consider cementite, which is a chemical compound and contains 6.67% carbon.

Figure 6 represents the microstructure of a piece of cast steel which contains about 0.30% C. The white grains are ferrite and the black grains are pearlite. Note that the grains are very large and angular and therefore subject to fatigue and impact.

Figure 7 represents the microstructure of the same steel shown in Fig. 6 after it has been reduced by hot working to bar form and polished in the direction of rolling. Note the banded effect—that is, the parallel bands of ferrite and the bands of pearlite which run in the direction of rolling and impart to the material decided directional properties.

Figure 8 shows the microstructure of a transverse section of 0.50% C. steel which, after having been hot rolled down to a rather small bar, was heated to about 1000° C. and slowly cooled in the furnace. The black areas of pearlite occupy more than half of the total area—compare this structure to that shown in Fig. 7 and the effect of a small increase in the carbon content on the microstructure will be noted.

The photomicrograph shown in Fig. 9 is of annealed eutectoid steel. It is 100% pearlite, contains about 0.85% C. and has a tensile strength of about 115,000 pounds per square inch. The white lamellae are cementite and the black lamellae are ferrite.

Cast hyper eutectoid steel (at a magnification of about 50 diameters) is shown in Fig. 10. Note the very large grains of pearlite surrounded by films of white brittle cementite. Long needles of cementite also project into the pearlite grains. The microstructure of this same cast steel (at 100 diameters) after having been hot-rolled down to small bar size is shown in Fig 11. The structure is entirely different and the steel would be much more satsifactory with regard to physical properties in every respect. These two photomicrographs show graphically the effect of hot work on cast steel.

Hot work is performed at temperatures above the critical range or the Ac_3 line but below the solidus line on the equilibrium diagram. The higher the temperature at which the hot work is done the softer will be the steel and the less will be the energy required for a given amount of reduction. Also the higher the temperature above the critical range at which the last work is done, which is called the "finishing temperature," the larger will be the grains when the steel has cooled to room temperature. The same fact holds substantially true with regard to heat treatment because the higher the temperature to which the steel is heated above the critical range, that is above the Ac_3 line, the larger will the grains become. While it is necessary in all annealing, normalizing and heat-treating operations to heat the steel above the critical range so that a solid solution of gamma iron and carbon or austenite will be formed, care must be

exercised so as not to carry to temperature very far above the upper *Ac* line.

The long columnar grains which grow at right angles from the surface of the mold in a casting or at right angles from the scarfed surface of the plate metal into the weld-metal may be refined considerably by heating one or more times to a temperature just above the upper *Ac* line of the equilibrium diagram followed by cooling to room temperature (see right-hand half of Figure 14).

In works annealing and stress-relieving operations we have quite different conditions with which to contend. In neither case it is necessary to heat the steel above the critical range. In stress relieving it is only necessary to heat the steel to a temperature high enough to soften it sufficiently so that the grains under stress will be able to reorient themselves so as to relieve that stress. A temperature of 1200° F. is usually considered sufficient for the stress-relieving of welds.

The pen sketch shown in Fig. 12 is representative of a deeply etched cross section of a fusion weld in mild steel plate depicting the disappearance at the weld of the banded structure which is inherent in the plate. The structure of the plate metal in this pen sketch should be compared to the structure exhibited in Fig. 7.

The schematic diagram, Fig. 13, shows how the weld metal and the adjacent plate metal would appear under the microscope (1) immediately after welding and (2) after the weld metal and plate had cooled to room temperature. The weld metal will consist of long columnar grains of austenite immediately after welding and these long columnar grains will break up into smaller grains, still retaining their original outline as cooling continues through the granulation zone from the solidus line to the upper line (Ar_3) of the critical range. The plate metal in the fusion zone adjacent to the weld-metal will also be austenitic immediately after welding and the rapidity with which it is cooled through the critical range will determine the structure at room temperature. If the base metal is thick and cold and the welding is done rapidly the fusion zone between the weld-metal and the plant will be cooled rapidly and if the carbon content is appreciable the area will become martensitic and hence very hard and brittle. On the other hand, if the plate is rather thin, or has been preheated, the cooling rate will be very much slower and the resultant structure of the junction area between the weld-metal and the plate may be sorbitic, which is much softer and more ductile. The rate of cooling of the weld metal and the adjacent zones will therefore determine the resultant physical characteristics just as they are determined by the rate of cooling during a heat-treating operation. The affected junction area, as it appears at room temperature is shown in (2) side of the sketch.

Assume now that a multiple layer weld is to be made rather than a single-pass weld. The right-hand half of the sketch in Fig. 14 depicts the effect of the second layer on the structure of the first layer. The temperature of the first pass is raised above the critical range while the second pass is being made and the long columnar grains are refined, somewhat, stress-relieved and possibly normalized by the heat treatment they thus receive. A multiple pass weld should be better than a single pass weld without any subsequent heat treatment.

The composite photomicrographs with the approximate temperatures indicated (Figs. 15 and 16) are more or less self-explanatory. They show how the microstructure varies from that which existed in the original plate metal up to the fusion zone.

Having traced through the changes occurring in the microstructure in all stages of manufacture to the welded joint, we see how the changes are at once complete yet follow definite rules. An understanding of these rules is essential for an understanding of the metallography of welds in steel or any other metal.

STRUCTURAL STEEL WELDING*

By GILBERT D. FISH†

THE questions most often asked about structural welding give a fairly plain idea, as to what engineers want to know before making use of this process. Perhaps as good a way as any, to deal with this subject in a half-hour talk, is to state some of these questions and attempt to answer them.

The one most frequently heard is this: *How do you tell a bad weld from a good one?* A less polite form is: *Can you tell a bad weld from a good one?* By visual examination of completed welds, a trained inspector can pick out any which may be seriously deficient in strength. In segregating welds to be made over or reinforced, he includes all those which he cannot pronounce unquestionably sound, even though this picks up a proportion of borderline cases which would be all right if left alone. He is not able to gage with certainty the strength of individual welds within ten per cent, but by passing only those welds having correct appearance, he can be confident of rejecting any which may fall below standard strength by as much as twenty-five per cent. In well ordered practice, qualified welders rarely produce welds below that limit and most of the rejections by inspectors are for relatively slight deficiencies.

With good welding electrodes and properly adjusted machines, the principal cause of strength variation is incomplete fusion of the weld root. Lack of fusion at the edges is uncommon and is easily detected, but a limited degree of weakness can result from imperfect root fusion. Experience has shown, that well-fused edges, correct contour, a bright surface having uniform ripples and freedom from burned spots and pores are sufficient insurance against concealed defects of serious magnitude.

Is it necessary to cut out and replace welds which fail to pass inspection? In rare cases it is necessary or advisable; ordinarily it is sufficient to reinforce a weld by cleaning it thoroughly and welding over it so as to increase its size.

Is it permissible to weld gas-cut edges? Yes, subject to thorough cleaning before welding.

Must welding be discontinued in wet, freezing or windy weather? Such conditions are unfavorable but do not make good welding impossible unless severe. Usually

* Outline of Lecture presented Feb. 21st at New York Section Lecture Course at Brooklyn Polytechnic Institute.

† Consulting Engineer.

weather bad enough to interfere seriously with satisfactory workmanship is so uncomfortable that the men quit anyway. If welding must be done at temperatures around zero, the steel should be preheated.

Is the personal factor among welding operators a serious problem? It is important enough to require systematic care in selecting operators. However, among those who pass the customary qualification tests and have satisfactory experience records, the variation in skill is not great enough to make safety control difficult.

Has structural welding been widely practiced? Fairly extensive applications have been carried out in most, if not all, countries where steel construction is considerably used. The United States is far in the lead in welded buildings, having put up two hundred or more, but has been left far behind by Germany in the field of welded bridges.

Is welding well adapted to some types of structures but not to others? This is not the case, although welding has important steel-saving advantages for certain structural forms, such as plate girder, trusses, wind bracing and continuous beams. The earliest welded buildings were factories. Of the first two welded bridges, one was a truss bridge and the other a plate-girder span. Numerous multi-story structures of office-building type were welded, not only in the east but also in Texas and California, before the depression interrupted such construction in 1930. There followed a number of years, during which most of the opportunities for welded building construction were in the institutional field. Yale University was a leader in welded college buildings and was followed by Vassar, Mt. Holyoke, Rensselaer Polytechnic, Trinity and Amherst. Numerous schools and some hospitals have been welded.

Is a structure designed the same for welding as for riveting, except the connections? Beam-and-column framing may be designed the same, without sacrificing any important economies, unless continuous-beam construction or rigid-frame treatment is involved. On the other hand, it would be very wasteful to design welded plate girders, trusses or wind bracing as for riveting.

Aside from such special features as those just mentioned, which are absent from many buildings, does welding save any expense in comparison with riveting? Some men having experience with both methods have for some years been saying that it does not. Judging by many cost comparisons, made by steel fabricators especially active in welded construction and lacking any motive for favoring it except to save expense, I believe welding to be more economical than riveting, even when the choice does not affect the design of the main members. The cost differences are small in such cases, else the question which is the less expensive would not be controversial.

Is welding worth using for special purposes, in structures which are otherwise welded? Frequently, yes. Aside from the broad question whether it would be better to weld the entire structure in shop and field, there are some kinds of shop details, which all fabricators agree can be more economically welded than riveted. It is also common knowledge, that field connections to old steel ought to be welded in order to avoid drilling the old members and the difficulties of accurate fitting.

Has avoidance of riveting noise been the principal motive behind the use of welding for buildings? Undoubtedly it has strongly influenced the building committees of universities, schools and hospitals, but cost comparisons have dictated the choice of welding in a large proportion if not a majority of the structures which have been welded up to now. The economic factor is the more important one and will influence the growth of welding increasingly as the margin of saving widens.

Is welding permitted for buildings by all cities? Presumably not, inasmuch as the building codes of many cities have not been revised in recent years. However, it has been found possible in many such cities to obtain special permits to weld; in fact, such applications have rarely been denied. Many of our large cities and hundreds of small ones have suitable provisions for welding in their codes. New York has joined this group as of January first. It is doubtful if any city will hereafter place serious obstacles in the way of welding, even if they delay amending their building codes to provide for it.

What are the provisions of the new New York Code, regarding design of welded connections? They are the same, word for word and figure for figure, as early editions of the AMERICAN WELDING SOCIETY Code for Fusion Welding and Gas Cutting in Building Construction. Some amendments in the 1934 and 1937 editions were not incorporated in the New York Code. As far as designing welded construction is concerned, good welded building practice as it has been carried on for some years in this country will be acceptable under the New York Code.

Does the New York Code prescribe any limitations or impose unusually severe restrictions on welding? There are no limitations whatever on the applications. As to restrictions, it is the intention of the Board of Standards and Appeals, charged with the formulation of the rules under which welding will be practiced, to require strict examination of all welding operators applying for certificates of registration, inspection of all welds by competent persons and certificates from responsible engineers that designs and workmanship are safe and strictly in accordance with the Code.

Is it now possible to obtain permits for welded buildings in New York? Applications are about to be filed for several such permits in three of the Boroughs, Manhattan, Bronx and Queens, covering buildings already under contract. The Manhattan project is a fourteen-story apartment house and the others are public schools. There is no way to tell how quickly permits can be obtained, as the Board of Standards and Appeals has not yet issued its rules, but there is likelihood that the new system will be placed in operation very soon. It is at present assumed that details of proposed welded connections are necessary additions to the usual framing plans, in applying for permits.

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JIGS AND FIXTURES FOR WELDING*

By H. E. DAVIES†

DEFINITIONS

JIGS and Fixtures for Welding are devices used to locate and control the component parts of welded assemblies while in process.

The associated terms "Jigs and Fixtures" seem to have been carried over together from the machine shop into the field of welding. In machine-shop nomenclature there is a well-marked distinction between a Jig and a Fixture; the former provides means for locating and securing the work material, together with means for guiding and controlling the cutting tools; the latter provides only means for locating and securing the work in correct position for either cutting or assembly operations.

In welding operations, no such distinction exists, since the tool is a blowpipe or an arc electrode, either manipulated by the operator or being a part of a welding machine quite independent of the work holding device.

It would appear, therefore, that all such holding devices which are more complex than simple clamps should properly be called Fixtures. The two terms, however, are rather indiscriminately applied, Jig being generally favored among persons engaged in the work, except for devices having a distinctive mechanical characteristic, such as turntables, mandrels, spreaders, etc., which are called by their usual names.

The general term "Welding Tool" will be used to include the gas blowpipe, the arc electrode and the contact tips of electric resistance welders, except where the reference is to one of them specifically.

ECONOMICS

In the application of welding jigs, the same rule governs as in other manufacturing processes: the cost of making and maintaining the device must be justified by the economy resulting from its use. Thus, a given product in small quantity may best be made in the simplest of clamping devices, at high labor and supervisory costs, while the same product in large scale production may justify elaborate fixture and machine equipment. As in other lines of endeavor, there are occasional examples of articles which, even in small quantity, require relatively expensive fixtures in order to attain the desired quality.

Probably because of the greater number of variables, forecasts of the performance of welding fixtures appears to be less dependable than for machining operations. Therefore, a greater margin of error must be accepted in determining how much special fixture work a given job will justify.

* Presented at Joint Meeting, New York Section, AMERICAN WELDING SOCIETY and Machine-Shop Practice Division, American Society of Mechanical Engineers, Jan. 15, 1938.

† Pollak Manufacturing Company.

CLASSIFICATION

1. Simple General Purpose Clamping Means

The simplest combinations of ordinary elements will often suffice for quite extensive jobs of fabrication. E.g., a piece of structural angle selected for straightness, with small pieces of flat steel for bearing pads, makes a very good V-block in which tubes or bars may be aligned for butt-welding. Machinists or carpenters hand-screws will serve for clamping small sizes and pipe-fitters chain vises for large ones. Almost every sort of material and accessory available about the shop will be found useful, either in its original condition, or with a small amount of assembly work, usually accomplished by welding.

2. Adjustable Multi-Purpose Jigs

In the case of products which are of one general design, but of different dimensions, and which are required in small or moderate quantity, it is often economical to use jigs which are adjustable in dimensions by arrangement of parts, such as telescoping, overlapping or reversible sections. E.g., internal spiders with adjustable radial arms for supporting cylinders of various diameters. E.g., a jig for fabricating structures of tubing, such as are used in aircraft, required in only moderate quantity, and with frequent changes and modifications. This jig consists of a bed-plate with upright columns at intervals on a longitudinal center line. To each upright are clamped two or more tubular cross-arms, adjustable for altitude on the uprights, and on each cross-arm are two or more work clamps adjustable both axially and circumferentially on the cross-arm. These clamps, therefore, can be so placed as to support and locate work of almost any dimensions within the over-all limits of the jig. E.g., jigs for the fabrication of aircraft exhaust collectors. This product is required in small or moderate quantities. For any given engine, certain dimensions such as cylinder port locations are constant, but nearly every other feature varies widely in order to accommodate the various aircraft in which the engines are mounted. These jigs consist of a base plate on which are permanently located fixtures representing the cylinder ports and the essential clearance requirements of the engine. There are also groups of dowel and bolt holes arranged in numerous radial and angular positions. These holes receive the base fastenings of movable brackets adapted to support the main ducts and branches of the exhaust collectors in any required position. The ducts and branches are so far as practicable assembled from standardized tubular and stamped parts. These exhaust collectors are often made of corrosion-resistant material having low thermal conductivity, high coefficient of expansion, and high welding temperature. Hence, it is often necessary to provide these jigs with compensation for the expansions which occur during welding and for the shrinkages resulting from cooling of

the welds. The method of compensation will be discussed under the heading of detail design.

3. Special Purpose Jigs

A product which is made in large quantity tends to justify, and require, the use of jigs and other equipment made especially for it, and having little or no utility for any other purpose. This holds true for welding operations as for machining, subject to the qualification that while machining fixtures are usually found satisfactory as first designed, welding fixtures often develop unexpected and unpredictable difficulties, sometimes quite expensive to correct. It is, therefore, better, when tooling up a new product, to lean toward the side of simplicity, and to add refinements if found desirable after the job is in production.

Many elaborate and expensive jigs have proved unsatisfactory and have been discarded.

Certain products in very large quantity are most economically made on fully automatic welding machinery. While this is in the class of special purpose equipment, it is outside the scope of this paper, and suggestions on design made herein do not apply to it.

TYPES OF JIG

All welding operations tend to set up in the work strains resulting from thermal expansions and contractions. The severity is usually greatest in blowpipe welding, least in electric resistance welding, and intermediate in electric arc welding. Hence, the remarks concerning the treatment of these strains apply in varying degree to jigs for the different methods of welding.

In a few instances the strains are small and symmetrically disposed, and may be entirely neglected. In the case of soft ductile materials, distortions may usually be corrected by cold work after welding, and present no serious problem. The strong non-ferrous alloys, and the stiffer grades of steel, especially corrosion-resistant steels, require careful consideration of the type and design of jig.

1. Tacking jigs are usually simple in construction and serve to hold the work components in correct relationship while they are lightly fastened together with tack-welds or with electric spot-welds. The work is then removed from the jig and the welding completed without further restraint of the work. The form and dimensions of the completed article are dependent upon those of the work components, together with the effects of welding. It is necessary, therefore, to make correct allowances for distortion and to establish the appropriate welding technique and maintain it.

2. Jigs in which the work is held until finished exercise a much greater range of control over the product than do tacking jigs. They are frequently depended upon to control distortions, and to counteract the effects of minor variations in welding technique. The methods by which this is accomplished are numerous. A few will be briefly described, with simple examples by way of illustration.

(*a*) Important dimensions of the product maintained, and deformations allowed to accumulate where least objectionable. This method has limited usefulness. E.g., a curved duct with flanges for attaching to associated parts is made in a jig which rigidly controls the positions of the flanges, and loosely controls the other components. All welding strains are accumulated in the curved portions of the body resulting in some variation of dimensions thereof but the product is interchangeable as to its essential dimensions.

(*b*) In which numerous welds are made and dimensions are maintained by the expedient of progressive clamping in a rigid jig. The initial weld is made with the parts clamped in correct position with respect to this weld alone, all other clamps on the jig being open. Any distortion resulting from this weld is immediately corrected, either by heat or by cold work. The next weld in order is then clamped up and made, and distortion corrected; and so on throughout the job. A convenient example is a ladder or a truss in which the transverse members are clamped up and welded one at a time to both stringers. Thus, the shrinkage resulting from each pair of welds is taken up by longitudinal movement of the free length of the stringers, and on completion of the last weld, the product is accurate in dimensions and free from internal strain. If a job of this sort were attempted by setting up all clamps of a rigid jig before starting to weld, the accumulated shrinkages would appear in the finished work when removed from the jig.

(*c*) In which the work is fully secured to the clamping devices before welding is begun, but these clamping devices, or at least some of them are not fixed on the rigid structure of the jig, but are free to move within limits and in a controlled path. This method is especially useful in handling thin sheet material having high coefficient of expansion, such as corrosion-resistant steels.

It is usually necessary or desirable to provide the movable work holding elements with keys or equivalent devices to lock them at will in either of two positions. The first position is for locating and aligning the work components prior to welding. The other position is used after welding for checking the finished work and making corrections if found necessary.

FORMS OF JIGS

1. Stationary.—Used for large work which is best done by the operator moving about the work, or, in some cases by two or more operators. It is sometimes convenient to control distortion by the simultaneous welding of opposite points of symmetrical work.

2. Freely Movable.—Used principally for fabricating small objects. The entire jig is moved about on the bench so as to bring the successive welding points into positions convenient to the operator. This form of jig is most usual in moderate quantity work, but sometimes finds a place in large scale production, where a number of identical jigs may be loaded and unloaded by a helper, thus conserving the operator's time.

3. Movable at Will by the Operator in a Path Controlled by the Fixture.—In this group are turntables, mandrels, trunnions, slides, rollers, etc., arranged to present the working points before the operator in sequence determined by him. They are sometimes special purpose equipment, but many are useful as multi-purpose devices fitted with adjustable clamping means or interchangeable accessories.

4. Power-Driven Devices.—Turntables, mandrels, conveyors, etc., which move the work in a controlled path at predetermined speed, which may be uniform, variable or intermittent, as required by the job. These are nearly always special purpose equipment for production jobs which, though large, do not justify the use of fully automatic machinery, or which by reason of form or material are not satisfactorily handled by available automatic welders.

GENERAL DESIGN CONSIDERATIONS

Certain general considerations apply to the design of jigs of all classes, types and forms.

Simplicity, both in construction and in operation is a great advantage. The jig should be no more complex than is actually required for correct functioning. Its use should be readily understood by the operator. Misuse, errors of procedure and mislocation of work should be guarded against, so far as possible.

Its operation should be accomplished by convenient and natural motions, without excessive physical effort, and with minimum risk of burns or other injury to the operator or to persons in the vicinity.

Structural and work holding parts should not unnecessarily obstruct visibility of the work nor interfere with normal manipulation of the welding tool. The operator should not be obliged to assume inconvenient or fatiguing posture.

The jig should have reasonable durability of mechanical parts and resistance to deterioration by heat. When, after long use, it approaches unserviceability, the fact should become apparent before spoilage of work results. If intended for use beyond the life of the original wearing parts, provision should be made for economical reconditioning.

If for intermittent use, attention should be given to safe and compact stowage, with provision for securing loose parts and accessories, and there should be clear and dependable means of identification.

It is especially important that such jigs be safe against misassembly when brought out for use after long idleness, since there may have been changes in personnel in the meantime.

These general considerations seem obvious in principle, but are sometimes quite difficult to reconcile in practice, and good judgment is required in making a satisfactory compromise.

DETAIL DESIGN CONSIDERATIONS

First, the base-plate, frame or other primary structure must have enough stability to retain its form and dimensions under the most adverse conditions that it will encounter, whether in service or in storage. The forces tending to deform it may consist of clamping strains, shrinkage or distortion of the work, the weight of the work in the case of large heavy jobs, and possibly the weight of the operator stepping or leaning upon it in the case of light jobs. Also there is the possibility that temperature changes in the jig itself will give trouble. This last condition cannot be successfully resisted but must be compensated by either automatic or manual correction, or eliminated by temperature control.

Work locating and clamping elements should be so designed and placed as to provide security against accidental movement or careless misplacement of work.

It has been learned through experience that, notwithstanding careful preliminary study, the behavior of work in a welding jig is not fully predictable. Therefore, means should be incorporated for correcting or adjusting the position of at least some of the clamps and locating points. These adjustments when made should be definite and secure, and should not be of such a nature as to be a source of inaccuracy and variation. A typical means of accomplishing this is to mount the clamp or locating point on a small independent base which is bolted to the main structure of the jig. Substantial clearance is provided in the bolt-holes, permitting a limited amount of adjustment in position. After finding the best position experimentally the small base is dowelled or tack-welded in place. Shims and packings are useful for making adjustments, but are a potential cause of error unless so fastened to their associated parts as to prevent careless omission or misplacement. Adjusting wedges and screws with lock-nuts are simple and convenient, but offer opportunity for tampering and accidental misadjustment. Definitely dimensioned spacers are better.

The fact that clamps and locating points as well as other parts, may absorb heat should not be overlooked.

It may be necessary to investigate the influence of temperature changes which occur during the working cycle and also those which accumulate during the daily work period, and to control or correct them. E.g., small movable jigs are often dipped in water after each cycle. Large or high production equipment may require either preheating or artificial cooling at certain points in order to maintain an accurate product and satisfactory working conditions. Thus, a massive jig body when cold may abstract too much heat from the adjacent work material and if allowed to become too hot may cause extreme discomfort or even hazard to the operator.

Surfaces which come in contact with the work should be of a quality which will not cause scars or deformations. Some materials, notably aluminum, are easily marred when hot.

Bearing pressures of clamps and locating points should be controlled within suitable limits, and should have ample areas in contact with the work to prevent local damage. Clamping pressures may be controlled by providing spring loading somewhere in the locking mechanism, or by proportioning the clampfingers themselves to have large deflections when locked.

Clamping mechanisms, like all other parts, should be as simple as practicable, consistent with dependable functioning, convenient operation and satisfactory durability.

It is always desirable to keep working parts of clamp mechanisms away from heat, and often advantageous to operate a clamp from a remote point. E.g., a thin sheet metal part of large area may be inserted into the jig, the operator using both hands to control its position meanwhile locking the clamps by pedal pressure. It may be noted that pedal operated clamping tends to conserve both time and energy, and reduces the risk of burned hands.

Actuating mechanisms for clamps vary widely. The simplest are of course the direct acting screw and the wedge. While these are reasonably satisfactory for many jobs, they have serious disadvantages for high production work. They are slow in operation, poor in mechanical efficiency, easily abused and often deteriorate rapidly, with attendant erratic behavior. It is usually better to select a mechanism which has the characteristic of increasing mechanical advantage as the locked position is approached, such as eccentrics, cams, cranks and toggles.

Clamping should be so designed as not to cause deflection of either the jig or the work, except where deflection is deliberately adopted as a means of controlling the form of the finished work. E.g., a butt weld joining the edges of thin sheets sets up strains which cause the finished work to bow concave to the working side. This may be counteracted by allowing the jig to bow the sheets in the opposite direction during welding. When the finished work is removed from the jig the release of tension in the working side allows it to lie flat. This method is also a partial corrective for the tendency of thin sheets to buckle and overlap.

When clamps make contact with the work very close to the welding point a special consideration arises. The material, contact area, and cross section of the clamp finger must be chosen with respect to the abstraction and dissipation of heat from the work.

Temperature changes in the work or clamp may cause movements or deflections. In such cases it may be necessary to provide the clamp with a floating anchorage, permitting it to move freely with the work in one plane while restraining it in others. This condition is commonly encountered in the fabrication of thin stainless steel sheet.

The matter of local temperature control in the work has an important bearing on successful welding, but usually has to be dealt with by welding technique and procedure rather than by design of the jig.

The machine elements of moving and power driven fixtures and equipment are governed by the ordinary principles of machine design, and rarely present any difficult or unusual problem.

In conclusion it may be well to remember that, at least in the field of manual operation, the best designed jig is useless without the skill of the welder, and that this skill is often obliged to make up for the deficiencies of poorly designed equipment. The correct selection of class, type and form of jig, together with careful detail design may have a very great influence on the technical and commercial success of a project, and are worth our best efforts. Welding is not a universal cure-all and there have undoubtedly been ill-considered attempts to apply it where other methods would have been better, but its field of usefulness is great and can be widened by continued study and development of methods and tooling.

Welded Foundation for Bronx-Whitestone Bridge

By CARLYLE H. SCOTT†

THE accompanying photographs show welded foundation cutting edges and caissons. These were completely welded; not a rivet used in either the cutting edges and caissons.

The two large cutting edges are 100 ft. long x 38 ft. wide. In addition there were two 38 feet diameter cutting edges. These were formed in sections, erected on man made islands and welded in the field.

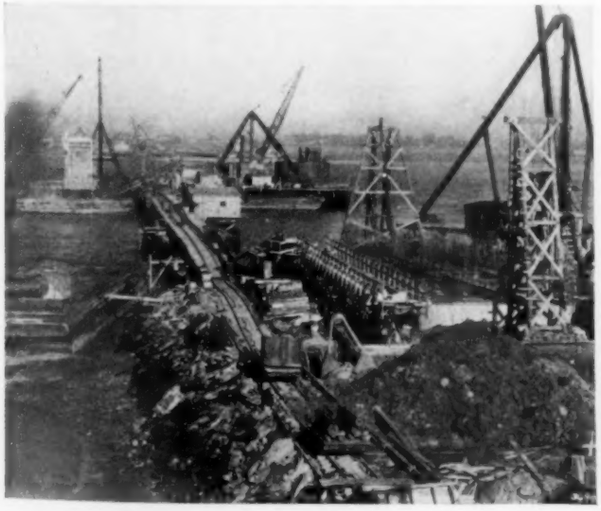
The two tower caissons were 38 feet square and 110 feet high on the steel section. These were formed in ten sections. The bottom section was completely shop erected and welded. It was then floated into position and nine sections, called lifts, were erected on top of the floating section. Each lift consisted of eight sections which were field assembled and all splices welded for strength and water tightness.

† President, Scott Welding Corporation.

The welding was performed by eight approved welders who passed a qualification test required by the Triborough Bridge Authority.

It required 23 weeks using 10,000 lb. of $^3/_{16}$-inch and $^1/_4$-inch shielded arc electrodes. There was approximately 40,000 lineal feet of varied welding consisting mainly of $^3/_4$-inch and $^1/_2$-inch butt welds and $^1/_4$-inch and $^3/_8$-inch fillet welds. One thousand tons of structural steel welded quickly, quietly and permanently.

Showing Tower Caissons with One Lift Being Erected



General View from Queens Side. Showing Cutting Edge Going Down Also Tower Caissons

Showing One of the Larger Cutting Edges Being Set Up for Welding

THE WELDING of the HIGH CHROMIUM and Chromium-Nickel Stainless Type Alloys*

By T. R. LICHTENWALTER†

IN THE past ten years the steel industry has perfected new alloys for those industries demanding materials to withstand temperatures and extreme corrosive conditions. These have been met to a great extent by the alloys containing chromium or chromium and nickel. The temperatures or corrosive conditions encountered govern the content of these elements and to meet certain conditions other elements, such as molybdenum, titanium, columbium and silicon are added.

The high chromium and chromium-nickel alloys of iron are generally known as stainless irons or steels. The stainless alloys can be classed in two groups: first, the straight chromiums, ranging from 11% upward, which are magnetic, and the chrome-nickel types ranging from 17% chromium and 7% nickel upward, which are non-magnetic in the annealed state.

The stainless alloys are highly resistant to most acids which are oxidizing in their nature, but reducing acids, such as sulphuric and hydrochloric, will attack them readily. They are also resistant to oxidation and scaling at high temperatures. They also retain their high physical properties at elevated temperatures.

For these reasons they are meeting increased demand each year in the chemical, oil, textile, automotive, food, dairy and many other industries requiring material with unusual corrosion and heat-resisting qualities. Stainless materials are supplied in plates, sheets, bars, strip, tubing, bolts, nuts, rivets, wire and many other shapes obtainable in common steel. They can also be rolled, drawn or formed into almost any shape or part as required by the fabricator, if proper procedures are followed.

The excellent welding properties of the stainless alloys are largely responsible for their present wide and diversified use. Both the straight chromium and the austenitic chrome-nickel types are readily welded. The straight chromium alloys are brittle in the as-welded condition and hence may crack if subjected to excessive shock or stress. The austenitic types are very ductile in the as-welded condition and can be bent or formed without difficulty.

As this paper covers the welding of stainless alloys, the oxyacetylene process of welding the straight chromium will be discussed first. Due to the low ductility in the as-welded condition, we must first look to the design of the part to be fabricated and lay out the joints where they will be subjected to the least stress. It may also be well to mention at this time that this is a good procedure to follow on any job being designed for welded fabrication.

The physical properties of all the straight chromium alloys are fairly comparable and the following is typical of a 16–18% chromium containing 0.12 max. carbon in the annealed condition.

Tensile Strength	75,000 lb. psi
Elastic Limit	50,000 lb. psi
Elongation in 2 Inches	25.0%
Reduction of Area	60.0%
Hardness Brinell	160
Thermal Conductivity	60% that of mild steel
Coefficient of Expansion	0.0000096 from 0 to 100° C.

From this it may be understood that both thermal conductivity and the coefficient of expansion are somewhat less than mild steel, and the job can be laid out using almost the same procedure as for steel. The lower heat conductivity will be found to give some trouble due to the warpage in the lighter gage, but this can be taken care of by proper design of joints and the use of welding fixtures.

The writer most generally spaces the joints about the thickness of the gage and uses 18–8 chrome-nickel type filler rod for tacking. The frequency of these tack welds depends on the length and type of joint to be made, and in some assemblies are as close as every inch. After tacking, the back side of the joint is fluxed and the weld finished by using the same type of filler rod as the sheet or assembly being made.

If it is possible to peen the weld while still hot, the ductility of the weld joint can be improved, and if followed by an anneal at a temperature 1450–1500° F., much more ductility can be attained. Annealing the fabricated part is not always feasible, but will increase the ductility, especially the alloys under 14% chromium.

The straight chromium types being generally used for elevated temperature and for corrosive conditions of the lesser nature seldom require annealing after welding except when used for nitric acid. If the equipment is to be used for nitric acid, the article should be annealed before putting into service.

Now we shall take up the welding of the austenitic chrome-nickel types which are most readily welded and possess great ductility in the as-welded state. The physical properties again are comparable to the 18% chrome plus 8% nickel type as follows:

Tensile Strength	85,000 lb. psi
Elastic Limit	40,000 lb psi
Elongation in 2 Inches	60%
Reduction of Area	65%
Hardness Brinell	140
Thermal Conductivity	40% that of mild steel
Coefficient of Expansion	0.000016 from 0 to 100° C.

Here you will note we have considerably lower heat conductivity and a higher coefficient of expansion than in mild steel. These two characteristics are troublesome to the welder who is not familiar with this type of alloy, but it is surprising to know how well he can control warpage if he understands the game and is willing. The design of the joint is a deciding factor, and where it is not possible to design to control warpage, fixtures are a necessity.

* Paper to be presented as Lecture No. 7, March 1st at the Polytechnic Institute of Brooklyn arranged by the New York Section of the AMERICAN WELDING SOCIETY.

† Republic Steel Corp., Alloy Steel Division.

Here again the writer generally spaces the thickness of the gage and uses numerous tacks, followed by fluxing the back side, proceeds with the weld.

In some instances, where only a short weld is to be made, say up to six inches, the job is spaced the thickness of the gage at the start, and a little over 1/4 inch per foot spacing is used to take care of expansion. It is well to tack the end first, starting weld at open end, then proceed in the direction of the tack. If this is not done, you may find yourself looking at a space twice as wide as you had originally allowed for or just the reverse. Chrome-nickel types of stainless, due to the aforementioned pecularities of physical properties, must have the weld laid down in a uniform manner. The speed should not be too fast, as this will generally close the gap, where too slow a speed opens it. The amount of heat is also a governing factor. Excessive heat tends to increase the gap and also lays down an excess of required amount of weld metal.

The actual welding operations for both types of stainless are practically the same. Equipment should be in good condition, the regulators should maintain an even flow of gases and the blowpipe should be capable of delivering a uniform flame.

As stainless materials melt at a lower temperature than mild steel and also have lower conductivity, a welding tip with an orifice one to two sizes smaller should be selected rather than that used for the same thickness of mild steel. The flame should be adjusted so as to show a slight excess of acetylene. 1/32 to 1/16 inch of acetylene feathers will be found to give best results. This adjustment will not carburize weld metal excessively and will maintain a reducing atmosphere over the molten pool, preventing the oxidation of the chromium.

As previously mentioned, the back side has been fluxed using specially prepared flux. This flux, as the weld proceeds, forms an envelope, preventing oxidation of chromium at this point, thus enabling the operator to obtain full and uniform penetration of the weld metal throughout the joint.

Bare filler rods are best suited for oxyacetylene welding and should be kept out of the welding cone of the flame and brought in for metal addition only when needed, but still keeping it protected in reducing atmosphere of flame envelope. This will protect the end of the filler rod from being oxidized. Some welders remove the end of the filler rod completely out of the envelope. This can be done by those welders who understand the peculiarities of molten stainless by making sure that the end of the filler rod is not molten before removing from flame. The weld should proceed with very little puddling, the tip of the welding cone almost touching the molten pool. The joint can be knit together by a back and forth motion. However, the round and round motion so often used for welding mild steel will give a spongy weld, which often will not be noticed until after the fabricated article is in service.

Most welders run into difficulties at the end of a weld due to a deep crater or hole all the way through the seam. They also have the same trouble when patching or spotting leaks. This can be readily overcome at the end of a seam by running out on the end of the filler rod. The best way to finish a weld or a spot is to raise the blowpipe slowly away from the molten pool, allowing it to solidify while still protected by the reducing flame.

The setting up for electric arc welding, so far as design and placing of joints is concerned, is much the same as for oxyacetylene welding. The seams should be so placed that they will not be overly stressed and in such a position that available grinding and polishing equipment can be readily used without difficulty.

Welding fixtures should be used to obtain the best finished jobs on those assemblies where thickness of material is too light to control warpage by welding procedure. There are numerous assemblies now being made by the metallic arc process as light as 22 gage. Very efficient fixtures are used and motor generator sets having very close control for this type of welding are now available. The thicker gages of sheets and plates require no fixtures, but procedure of welds should be carefully studied so that warpage can be controlled and a neatly assembled article is the final result.

The electric arc welds on the straight chromes will be brittle and the writer generally uses the following procedure to weld this type of stainless.

The design of the assembly is carefully laid out to place welded seams where they will be stressed the least. The joints are spaced the thickness of the gage where welds are to be made from one side only. The joint is then strongly tacked, using a proved quality austenitic chrome-nickel type of flux coated arc welding electrode and then finishing the weld by using an electrode of the same analysis as the stainless being used for the assembly. Peening the straight chromium welds, followed by an anneal, will increase the ductility.

The austenitic chrome-nickel types of stainless lend themselves readily to the metallic arc process of welding. The asemblies are laid out in much the same way as previously stated. Numerous tack welds are used to maintain the proper spacing of the joint to be welded and the electrode should be the same analysis as the type of stainless being used. The finished weld, if properly made, will be sound and free of porosity along with excellent ductility. Annealing of the finished assembly is seldom required and is recommended only in isolated cases where it is absolutely essential.

We will now discuss the general procedure used for the welding of stainless. The joint layout is much the same as that for mild steel; light gages of sheet up to 14 gage are generally made using one pass. Heavier gages from, say, 14 to 10 gage or up to 3/16-inch plate are generally made using two passes, one on each side of the joint. Plates 1/4 to 1/2 inch in thickness should be scarfed and multiple passes be used—a 1/2-inch plate requiring five to six passes. Plates heavier than 1/2 inch should be scarfed from both sides, welding passes to be alternated from one side to the other.

Straight line welding with a minimum of puddling should be the procedure on all stainless welds. Where multiple passes are to be used on the heavier sections, the slag accumulation from each pass should be cleaned off before laying down the following layer of weld-metal. Again on multiple passes it is preferable to lay down string beads rather than attempt to puddle in a full layer of weld metal across the gap.

Mild steel reinforcing members and steam or water jackets can be welded to stainless using austenitic chrome-nickel type electrodes. Care should be taken not to burn through the stainless shell when doing this type of welding. If galvanized reinforcing members are to be used, the zinc coating should be removed in the vicinity of the weld to obtain good uniform fusion.

On some assemblies it will be found necessary to have copper or copper alloy fittings attached to the stainless. Ordinarily the intimate contact of such unlike materials is not recommended. However, on some types of assemblies service tests have given no trouble due to galvanic action causing premature failure. When it is found that the assembly requires non-ferrous alloy fittings, the fabricator should ascertain how the finished article is to be used and present this story to the mill making the stainless for their comments. This will pre-

clude a possible embarrassment if the finished job were put in service and failed to stand up due to electrolysis. This service is available from your source of supply and should be taken advantage of.

The actual joining of copper to stainless and also in some assemblies, such as automobile steering wheels which is steel to polished stainless, a special silver solder melting at a temperature around 1100–1200° F. is used along with a flux that will reduce the oxides formed on the stainless at this temperature. The oxyacetylene flame is used for joints of this nature. Stainless materials are especially suited for assembly by spot and seam welding. The material is free from scale and often used in polished finishes. You will find spot and seam welded assemblies ranging from small metal slips to streamlined trains.

Due to the higher hardness of stainless materials, the ordinary copper electrodes do not stand up well and the harder type of electrode material is recommended. Also, due to the lower melting point, less heat is required to make the welds. A large flat electrode is recommended for use on the face side of the finished article to eliminate the depression left by the contracting metal.

For resistance and flash welding less heat is required and for automatic welders the design of the operating cam will have to be changed to taper off the upsetting action after the parts are brought together. The reason for this is due to the high physical qualities of stainless at elevated temperatures.

In the past few years the atomic hydrogen arc-welding process has shown that it is well adapted to automatic welding of stainless materials. Where large numbers of the same shape are to be welded, this process will be found advantageous from a production standpoint. The atomic hydrogen welds are smooth on both sides and often can be used as is after the light oxide scale is removed by pickling.

Generally speaking, it will be found that stainless materials require less heat for the actual welding operation. The time required to make a foot of stainless weld will also be found to be only slightly more than for mild steel. There will be an increase in setting up for the job due to the greater care required in handling, as most jobs require a bright finish in the finished assembly. These finished jobs range from ordinary pickled finish, cold rolled to bright polish, and the surfaces should be protected during fabrication.

After welding operations are completed, the scale formed by the welding heat should be removed from both sides of the welds. The ultimate use of the finished part is the deciding factor and the process of removal can be any of the recommended practices, such as pickling, sanding, or grinding and polishing.

In conclusion, let us state that a wealth of information is at hand from those firms manufacturing the raw materials. This is available for only the asking. This service not only covers welding, but all other fabricating and corrosion problems as well.

ARC CUTTING—PRACTICAL HINTS

By C. J. HOLSLAG*

CUTTING OF SCRAP

THE arc is particularly appropriate for scrap cutting, preparing metals for charging in the furnace, or for emergency cutting and the elimination of surplus metal. Metal up to 3 inches thick is theoretically more cheaply cut with the electric arc but in the case of gates and risers of mild steel, production is slowed down by the arc and ofttimes comes to a question of the enlargement of the building facilities for continuous plant production. The arc for this reason is generally not used. In the cutting of scrap the use of the arc depends on the current price of the scrap. Practically up to 1 inch thick is cut best by the arc if electric power is reasonably available. For isolated cases or where power installation is not advisable because of the intermittent nature of scrap cutting, gas in bottles is used more because of its easy availability because there are practically no carrying charges when not in use.

Gas will not cut all metals. For this reason, the cutting of non-ferrous scrap and some of the new special alloys, as well as cast iron, is very often accomplished by the arc method. A notable example of this type of cutting is stainless castings. It is practically impossible to remove gates and risers except by the arc process which is the method universally used. The arc process works very favorably in connection with the electric furnace work. The same power facilities used for electrical feed, the furnace lends itself admirably to heavy current arc cutting.

CUTTING IN CONNECTION WITH WELDING

Arc cutting is very popular for the preparation of welding shapes and plates. It is especially useful for cutting out a reverse side of heavy plate work or the removal of defects under cutting or overrun sections. For this work a metallic electrode is used, sometimes one with oxygen liberating chemicals imbedded in the coating. Very often a regular covered electrode is used with a current density raised so that it cuts instead of welds. Another trick is to make the electrode covering damp by dipping it in water which further liberates oxygen which aids in the cutting. Cutting with the arc leaves the edges suitable for subsequent welding. This is often used to prepare recalcitrant surfaces to weld so that after the cutting arc has passed over them they will then "take" the weld. It is especially true in high-carbon cast iron and special alloys. The first pass of the arc prepares the edges for subsequent welding.

THE HOLDER

The holder has much to do with the heating of the electrode and it is useless to use any more of the elec-

* Electric Arc Cutting and Welding Co.

trode than is absolutely needed to reach the work, because the passage of the heavy current makes it white hot, and all this heat represents a loss in energy. A very simple method is to grip the electrode in the jaws of the handle so that only about 3 inches of the cutting end protrudes, leaving 8 inches on the other side. As this end points and burns off, the cool and unused end is pushed through the jaw. Another method of keeping the ends cool is to grasp the electrode in the middle, and use it from alternate ends, thus cooling and heating each end successively. Still another method for accomplishing this, which aids materially in production on heavy work, is to keep a pail of water at hand, in which the entire electrode and holder may be immersed at intervals.

CUTTING HEAVY SECTIONS

Cutting, especially on heavy sections, is generally accomplished best from the underside, or from a vertical face, or, better still, from a plane tipped a few degrees from the vertical, so that the molten metal may flow away. A sluiceway must be provided for the molten metal to pass through, or it will solidify, and it is harder to cut through this slag metal than through the original good metal. The piece may be stood up or tipped at the proper angle for a cutting start. The direction of the cutting should be chosen so that a sluiceway is always kept open. This is especially easy of accomplishment in the cutting of cast iron.

There are some special cutting methods. Where the piece is not too thick, the cut may be made from the top downward, or horizontally from either edge. The cutting is accomplished by moving the electrode across the thickness of the work with a slow downward motion, flowing the melted puddle out of the trough, and, with a quick movement backward, starting downward immediately, so as not to allow the molten metal to cool. With this method, the piece must not be too thick to prevent the molten metal from flowing.

Where the piece is so thick that this method cannot be followed, successive "bites" should be taken off the corners until the cross section to be cut is small enough to employ the method previously described. If good "bites" are taken off, a free trough will always be provided for the flowing away of the metal.

THE ELECTRODES

Graphite, or graphite-treated "carbons" may now be had which will carry heavy current values, and these make this work perfectly possible. Cored, and "sandwiched" electrodes often prove themselves profitable, because they liberate oxygen, which combines with the cut metal to form gas. Rectangular electrodes, even without the oxygen compound "sandwiching," aid materially in cutting operations. An electrode of this type has the carrying capacity of a round electrode of much larger cross-section; it also greatly reduces the width of the cut, and hence the amount of metal to be removed.

UNDER WATER CUTTING

For cutting underwater both air and oxygen have been used in round and rectangular, carbon and graphite type electrodes very successfully. The combination of oxygen or air and the cooling allows a round electrode for one hole and a rectangular electrode with two or more holes to be used for cutting with gas, preferably oxygen, forced through, which aids the cutting at the tip and also by its pressure forces a space for the operation. The cable carrying the current is enclosed by the hose carrying the air or oxygen which hose both insulates and cools the cable. Pressure of the air or oxygen required is approximately 90 lb.; voltage pressure, minimum about 90 volts; more is required according to the depth. Currents 500–1500 amps.

RIVET CUTTING

The arc is used for cutting in replacing gondola car or ship plates wherein the metal that remains must not be scarred or cut. Carbon or graphite electrodes held at right angles to the rivet head will melt the rivet head cleanly without injuring the metal and the quick application of heat will so loosen the rivet that in a few moments it will fall out if rattled. The cost of this method is reasonable as shown by the table below:

Rivet Cutting Test

Rivets	$^{5}/_{8}$ inch average size
Cutting	$9^{1}/_{4}$ hours
Number cut	1,059
K.w.	110
110 Kw., 0.01 $^{1}/_{2}$	$1.65
Cost per rivet for Current	$0.0014
$9^{1}/_{4}$ hours, $0.65	$6.0125
$6.0125 divided by 1059	$0.0056 labor cost per rivet
9 carbons @ $0.13	
$1.17 divided by 1 059	
Labor cost per rivet	$0.0056
Cost current	$ .0015
Cost carbon	$ .0011
Total cost per rivet	$0.0082

World's Largest Span All-Welded Crane

The front cover shows a 15 ton, 120 feet 0 inch span Cleveland All-Welded Mill-Type Crane. This is one of 15 cranes of this span and design, ten of which are now under construction. To date these are the world's largest span all-welded cranes. All were built by the Cleveland Crane and Engineering Company, Wickliffe, Ohio.

Every major section, such as the two girders, the four end trucks, trolley, cage, etc., are fabricated into the rigid one-piece units by welding. No rivets are used. Bolts are employed to tie the major sections together only because of shipping and erection limitations.

Each girder weighs 72,000 pounds and has an actual over-all length of 122 feet 0 inch. Their manimum depth is 6 feet 6 inches. Steel plates up to $1^{1}/_{4}$ inch thick are used.

The hoist is provided with a 100 hp. motor, the trolley a 10 hp. motor and the bridge is equipped with two separate drives each of which is powered with a 45 hp. motor.

The complete crane weighs 275,000 pounds and is painted aluminum and black.

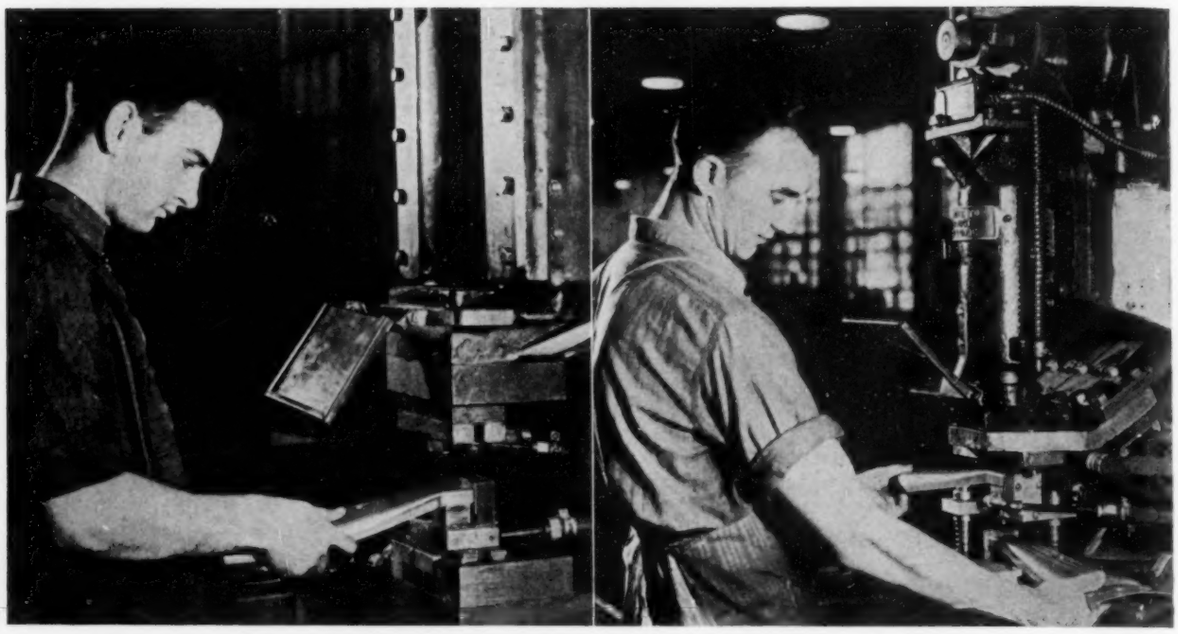


FIG. 1 WELDING CASTER SOCKETS TO WASHING-MACHINE LEGS
(These two views illustrate how an application of electric-resistance welding was changed from one assembly at a time (left) to two at a time (right) with an increase in output of 35 per cent.)

RESISTANCE-WELDING Fabrication

Spot, Seam, Projection and Butt-Flash Methods

By J. M. COOPER†

IN THIS paper, an attempt will be made to review the several forms of the resistance-welding process, pointing out the features characterizing each along with general comments covering applications and recent improvements. It is hoped that the extensiveness of the process will be made apparent and that it will be realized that modern resistance welding offers possibilities in practically every branch of manufacturing. The subject will be handled by discussing separately spot, seam, projection, and butt-flash welding.

The resistance-welding process is undoubtedly the outstanding fabrication process in the metal-parts industries, a veritable modern Aladdin's lamp that has accomplished feats of joining metals in a manner so simple, so quick, and so useful as to appear almost magical. What could be easier than merely to bring two objects together and, with a flash, have them unite, or to press them together at desired points of fastening and have an impulse of electric current bond them perfectly? This is precisely what modern resistance welding accomplishes in a manner that is as dependable and as understandable as any other machine-tool process.

Fundamentally, in the resistance weld, the welding action itself is based on the theory of the recrystallization of the metal. Heat is applied to bring the metal to a plastic state and pressure causes the grains to deform and grow across the interface boundary that separates the two pieces, resulting in a weld. The heat necessary to soften the materials is generated by the passage of a heavy electric current flowing through the resistive path of the metal, and the forging pressure is applied either by forcing the objects themselves together as in butt and flash welding or by the pressure on the electrode as in spot, seam, or projection welding. Resistance welding is therefore metallurgically ideal, inasmuch as the resultant weld metal has a forged or worked structure, differing but little from that in the original material. A modification in the generation of welding heat is found in flash welding, where a controlled arcing is set up between the parts being welded and the heat is the combined re-

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† Philadelphia representative, The Taylor Winfield Corporation.
Cuts loaned through courtesy of Mechanical Engineering.

FIG. 2 DIFFERENT TYPES OF COPPER-WIRE TERMINALS THAT WERE WELDED ON A PRESS-TYPE MACHINE USING TUNGSTEN ELECTRODE TIPS

sult of the temperature of the metallic arc and the current flowing through the resistance of the material adjacent to arcing surface. Nevertheless, plastic and not molten material is what is forged together, any fluid metal being forced out.

SPOT WELDING

By spot welding is meant the production of a highly localized weld or spot by a welding tip or electrode. This tip causes a concentration of heat and pressure of proper proportions to cause a weld. Although appearing in several forms, such as manual, foot, or motor-operated, and press, portable, jig, and Hydrospeed types, spot-welding apparatus is basically composed of a low-potential high-current transformer with suitable conductors for carrying current to welding tips, a system for exerting force on electrodes, and provision for turning current on and off at the proper instant in the welding cycle. Spot welding is ideally suited to sheet-metal goods and to metal parts of all descriptions, providing it is not justifiable to handle them as a projection or butt-flash weld.

Manual or Foot-Operated Spot Welder. This is the form of resistance welder that is most commonly used. Because the welding cycle is controlled by the operator's judgment, a certain degree of skill is required to operate it successfully. Fortunately, on light-gage sheet metal, required welding conditions can vary considerably and on this class of work this machine finds its most extensive use. A feature of the manually operated type is that the motion of the electrodes down toward the work is under constant control of the operator's foot and thus facilitates positioning of parts being welded, which is convenient on wire goods and on small parts. On high-production parts that are bulky and hard to handle, or that lend themselves to multiple-projection welding, the desirability of the manual spot welder is challenged by newer types of equipment.

Recent improvements in manual spot welding would include (*a*) use and appreciation of the new water-cooled alloy tips, (*b*) protection of slender welding tips through using short-duration current impulses which is made possible by weld timers, and (*c*) general improvements in spot welders themselves, such as water-cooled transformers, better leverage ratios, and lowered mass and inertia in moving parts.

Heavy-duty air-operated spot welders should be mentioned in this section because of the widespread extension of spot welding on $^1/_8$-, $^1/_4$-, and $^5/_{16}$-in. plate and angle-iron work. With these machines, the operator can obtain the necessary heavy pressures and may "pump" or interrupt the flow of current into a series of pulses which helps to break through oxides and preserve the points by allowing electrode water cooling to dissipate destructive heat accumulations. Special thyratron panels are also available which will interrupt the welding current into a series of pulses.

A rust-preventing paint has also been developed which will protect inside surfaces without interfering with welding.

Power-Operated Spot Welder. In this type the foot machine is simply motorized, offers faster operating speeds, causes less fatigue to operator, and reduces the skill required. These machines are mostly used on sheet-metal parts where many welds are made in rapid succession and where liberal clearance around both upper and lower arms is necessary.

Press Type of Spot Welder. This machine represents the

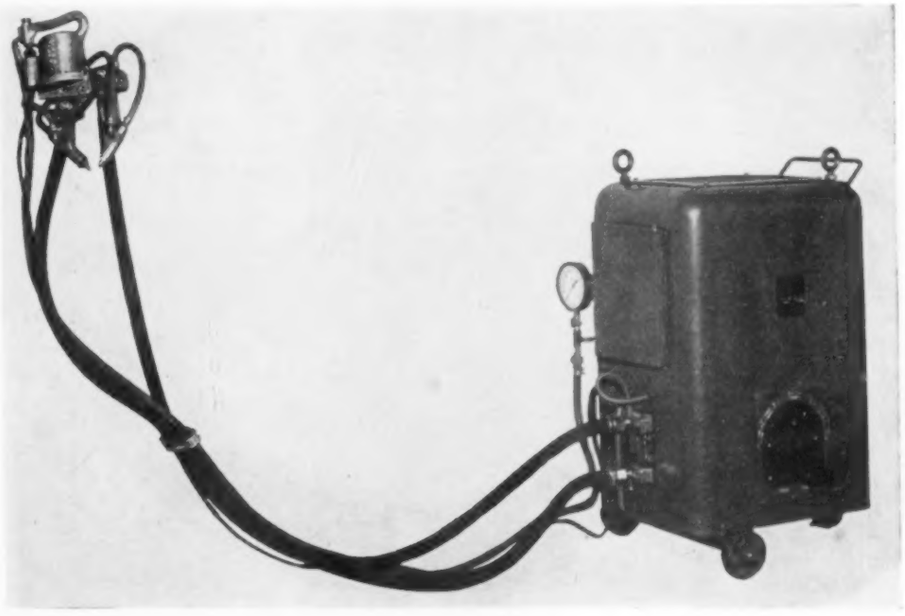

FIG. 3 PORTABLE SPOT OR GUN WELDER

(In this form of machine, the power is supplied by a stationary transformer through flexible water-cooled cables. It is used for welding bulky objects.)

most ideal equipment for spot welding, as it is characterized by (*a*) fully automatic mechanical operation, (*b*) a moving electrode held in a head that works up and down in a quill or slide, giving a true vertical motion to the electrode as differentiated from the arc through which the spot-welder arm swings, (*c*) low mass in moving parts so that impact to electrodes is lessened when operating at high speeds, (*d*) easily adjusted and calibrated pressure devices such as air cushions or springs, (*e*) readily adjusted timing cams when an external electronic control is not used, (*f*) 16 or more points of heat control, and (*g*) variable-speed drives. Many refinements of the press type of machine have made it practical to spot weld most of the nonferrous alloys such as the bronzes, brass, and aluminum. A characteristic product of the press-type welder is illustrated in Fig. 2. In conjunction with an electronic control, such as the thyratron or ignitron, it provides an ideal machine for spot welding stainless steel, a material requiring extremely short current duration to limit carbide precipitation, or for making one or two electrical-cyle welds on sheet metal which are noted for their lack of surface deformation and discoloration at the weld. Referring to the resistance-weld theory, metals only need to be heated to their plastic range of temperature so that under ideal conditions, the press welder will permit spot welding to be done with absolutely no sign of sparking or splashing out of molten metal. When metal is permitted to blow out from betwen two sheets, a contraction or shrink spot is formed, making finishing difficult.

Portable Spot or Gun Welder. This is a specialized form wherein a small yoke or frame carries the spot-welding dies along with an air cylinder to actuate the moving electrode, connection to a stationary transformer being made through flexible water-cooled cables as shown in Fig. 3. Such equipment has provided an invaluable tool for welding large bulky objects, of which the automobile body is a good example. It has also worked out ideally on moving assembly lines permitting welds to be made on the "fly." Gun welders are semi-automatic, the operator simply presses a valve actuating the cylinder and, when the proper pressure is exerted, a switch throws the automatically timed contactor and completes the weld. Rapid work can be done, as only from one tenth to one third of a second is necessary to produce a weld.

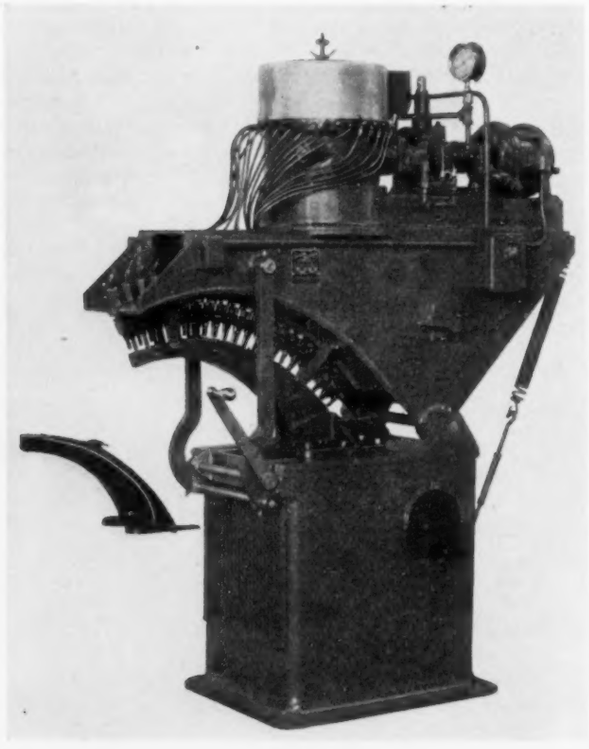

FIG. 4 THIS MACHINE CAN MAKE 42 WELDS IN SERIES

(Individual welding heads are mounted on the holding fixture and are brought into action rapidly and successively by oil pressure. Machines of this type can be supplied with 150 heads.)

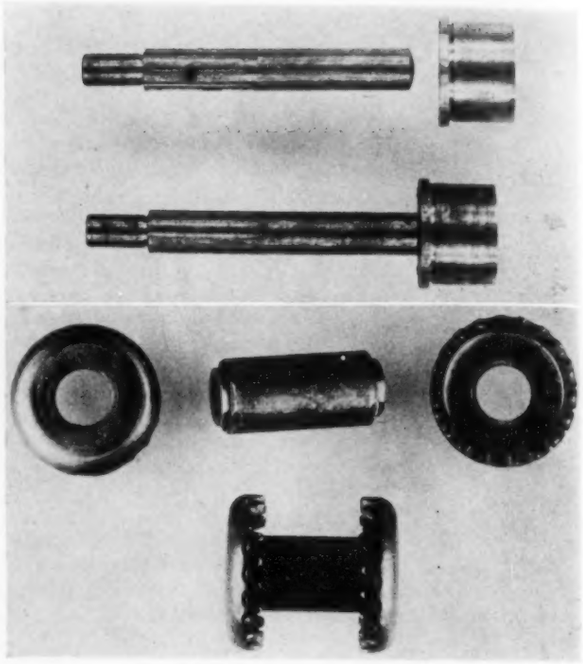

FIG. 5 TWO EXAMPLES OF PROJECTION WELDING

(Upper view shows a splined shaft before and after it was welded to washing-machine wringer-roll driving cup. The shaft, which is $^{9}/_{16}$ in. in diameter, has a radius on the end and was welded to within 0.008 in. concentricity with roll driver. Lower view illustrates use of projections that are swaged on the shoulders of a sleeve to permit welding of washing-machine wringer-gear stampings.)

Other forms of portable spot welder are used, these being mainly either an adaptation which is constructed so that the arms and machine itself can be swung in almost any position, making it truly universal, or a form of mobile welder arranged for series welding, the transformer and both electrodes being on one side of work while a shunting backup device is used on the other. Such machines are in use in the fabrication of bulky laundry machines and railroad cars.

Pry-Bar or Jig Welder. This is used extensively in the automotive field and may provide the answer to a difficult welding problem. In this apparatus, the sheet material to be welded is clamped in a copper fixture that constitutes one terminal of the transformer secondary circuit. The other end of the secondary is connected to a bar or rail that is bent up and around following the weld-line contour. A copper pry bar, equipped with welding tip, is brought to bear against the outside bus bar that it uses as a fulcrum and presses against the material at the location where a spot is to be made. Current is turned on by a switch located in the handle of the bar and the weld is completed.

Hydrospeed Spot Welder. This is a specialized apparatus having a multiplicity of individual hydraulically operated welding

heads mounted in various positions around the fixture that holds the object to be welded. Oil is shot into the different welding-head feed lines by a distributor valve and each head is brought into action in rapid succession. One welding transformer may serve for a large number of heads, the machine shown in Fig. 4 having 42 of these. However, a large machine, having over 150 welding points, would need several transformers in order that several welds on different circuits could be in progress at the same time.

SEAM WELDING

In a resistance seam weld, a continuous line of welding can be produced, serving the purpose of either sealing vessels pressure tight or providing a line of physically strong welding. Countless containers of every description, including automotive gasoline tanks, grease drums, paint pails, refrigerator evaporators, range boilers, and transformer tanks, have found increased strength and lowered costs in the seam weld. Many and varied forms of apparatus are used, machines having been built to suit almost every conceivable condition. In general, pieces to be seamed are passed in a lapped condition between two copper-alloy welding disks that concentrate the current along a narrow path.

Except in a few instances, the welding current is interrupted into a series of pulses that produce an alternate heating and cooling action in the weld metal, thus preventing excessive heat accumulations that might build up were the current permitted to flow continuously. The weld can be made on a lap or away from all edges. Speeds vary from approximately 3 fpm on 11-gage stock to 30 fpm on 22-gage. In all cases, surfaces at the line of welding must be clean and free of all oxides or scale. Stainless steel, aluminum, and brass can be seam-welded, providing consideration is given to the special conditions they require.

PROJECTION WELDING

By projection welding is meant that general class of welding wherein some kind of projection is processed into or on the part which will cause heat and pressure to localize for a weld without depending on the concentrating action of an electrode tip. As the spot-welding tip can be a prolific source of trouble, if not carefully maintained, the advantage of using a projection that consistently presents uniform size and conditions is obvious. It also makes possible multiple welds with a resultant increased production rate. In many cases, the mark left on the material by a welding tip can be eliminated by using an embossing on one of the parts and a broad smooth-surfaced electrode against the finish side. Several typical examples of projections that have been found useful for resistance welding will be discussed later.

As stated before, projections can be welded in multiple and, as this increases the transformer capacity and pressure requirements, and also necessitates accommodations for welding die sets, a new class of machines has been brought out to suit this work. Projection welders have die-holding platens, one of which is mounted on a rugged knee and the other on an upper head that moves up and down in close-fitting slides. Pressure can be applied through toggles or hydraulic cylinders, and its magnitude is readily adjusted. Large water-cooled transformers with cast-copper secondaries supply the heavy welding currents that are usually necessary. In all cases, the entire operating cycle of the machine is fully automatic, welds being usually made in a short time with a high energy input. As projection welding offers numerous possibilities and, therefore, finds so many varied applications, two of these being shown in Fig. 5, the equipment is made flexible as to adjustments of heat, pressure, and time, so that quick changes from one job to another can be made. Customary procedure is to invest in machines with sufficient reserve welding capacity to take care of the inevitable future heavier welding jobs. The automatic press-type spot welder offers an ideal machine for small compact projection patterns on light-gage parts. Dial or automatic feeding of projection welders is extensively done. Because current is not concentrated by the die itself, a welding alloy of copper and tungsten is generally used and gives long life to die sets.

TYPICAL EXAMPLES OF PROJECTIONS

The several sketches reproduced in Fig. 6 illustrate several useful projections that can be incorporated in the design of parts for resistance welding, (*a*) showing the simple and common form of projection. It is desirable to have a crown or dome so that the weld may start as a point contact and have a continuously increasing cross section to the finish of the weld. Size of the projection is determined by the strength required, number of projections used, kind of material and desired degree of freedom from marking, and size and space available for welding. No definite rule can be given. Each design must be based upon the particular factors controlling it. However, a few suggested sizes are given on the drawing. Care should be

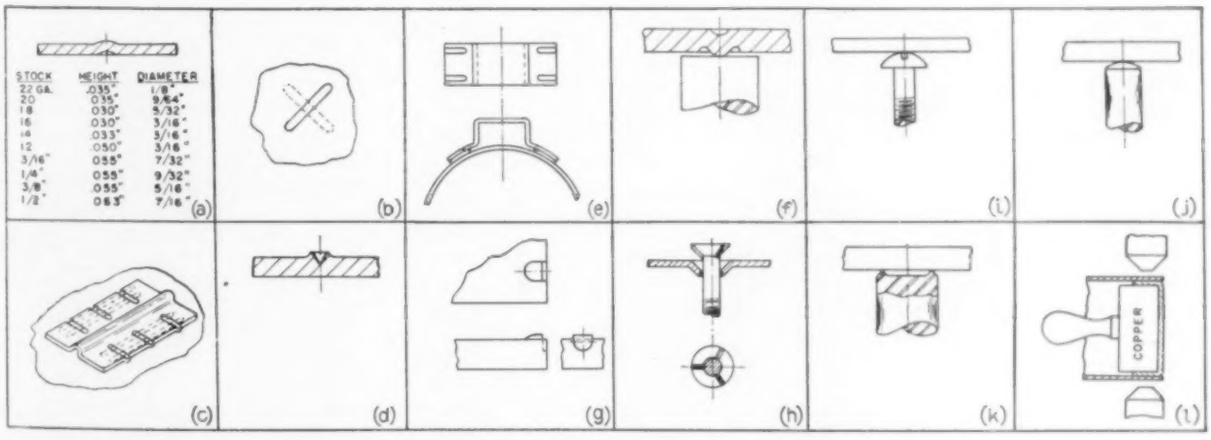

FIG. 6 TYPICAL EXAMPLES OF PROJECTIONS THAT CAN BE INCORPORATED IN THE DESIGN OF PARTS THAT ARE TO BE RESISTANCE WELDED

taken that the punch is the right size and is round-nosed so as not partially to shear a slug out. The embossing should be placed on the heavier of two thicknesses wherever this can be done.

Sketch (*b*) is the cross-elongated projection combination used on 24-gage and lighter sheet. This crossing of elongated projections facilitates welding. A practical application of this principle is the welding of handles to tin oil drums as shown at (*c*). In this case, the projections are ribs crossing at right angles.

The "prick-punch" projection where the rim thrown up around the punch mark serves as a suitable projection for welding light material to a heavier piece that carries the punch mark is illustrated at (*d*). Sketch (*e*) shows an elongated projection that is used on curved surfaces or other places where a slight longitudinal or transverse movement may occur. This projection is to insure ample contact surface in the direction in which the movement is likely to occur.

Sketch (*f*) shows a projection brought up on a heavy piece of material with a crater-like ring coined in around it. The purpose of the groove is to take any fused or upset metal and allow an intimate contact between welded surfaces. A scheme that is used for bringing a projection up from the side of a heavy section is illustrated at (*g*). This type is made by striking the edge with a punch whose face is half on the stock and half overhanging it.

How a cold-headed part can have ribs or any other suitable projection forged on it to facilitate welding is shown at (*h*). The countersunk hole in this case was used for location as well as to give good bearing to the flathead screw. A reminder of the ease with which studs and screws can be butt-welded to a surface is given at (*i*). A dome should always be present to cause the weld to start at a point and increase progressively in section. A shoulder behind the head is always handy to provide a bearing for the welding electrode. If studs are straight without this shoulder, then it is usually necessary to clamp the stud rigidly in an electrode. Sketch (*j*) is similar to (*i*), but is intended to represent heavier combinations. Merely doming a shaft end is not alone sufficient to butt-weld it successfully to another surface that is part of a heavy chilled section. An extremely high current density for a short time, such as might require an electronic control, is necessary to heat the heavier piece sufficiently to allow it to be welded and still not upset the shaft.

Sketch (*k*) shows an annular type of projection that is often put on screw-machine parts. Such a projection is also stamped into a pressed-steel part, such as in the case of the metal radio tube. It is suited mainly to the welding of light-gage materials. In heavier forms, it heats irregularly and is not as satisfactory as the dome type of projection. A series or shunt weld is illustrated at (*l*). In many cases, a shunt block would solve an assembly problem or make welding in an inaccessible place possible. It has the additional feature that two welds are made simultaneously.

BUTT AND FLASH WELDING

It is not always possible or desirable to fit metal parts together in such a manner as to present the overlapping fits or broad surface to the surface contacts that spot, seam, and projection welding require. Obvious cases would be the welding of rods, bars, forgings, and those sheet-metal or pressed-steel parts whose ultimate form cannot tolerate the disturbance in appearance that a lapped or prepared joint would cause. Here, advantage is taken of the fact that welding heat can be generated by the passage of current through the metal comprising the abutting surfaces of the objects. This heating occurs at the junction alone because it is here that the heavy flow of current meets its greatest resistance, a sort of electrical bottleneck condition. To increase this junction resistance, light pressure is provided, resulting in poor electrical contact. Generally, a still further aggravation to current path at junction is brought about by deliberately permitting metallic arcs to occur by separating the parts while current is flowing. This arcing or flashing serves two purposes; (*a*) it pronouncedly localizes heating to just that metal which it is necessary to have plastic, and (*b*) the arcing can be handled so as to burn away the first points of contact in an imperfectly butted joint, resulting finally in a continuous line of welding even though it might not have been possible to have provided perfect initial fits. Plastic metals in the butt-flash weld are forged together by applying an upsetting force through the parts themselves. Inasmuch as the extent of plastic metal is confined to practically only the surfaces of the abutting parts, a narrow and sharply defined upset results which in most cases can be readily trimmed off, leaving little to show where the weld occurred.

A few combinations of nonferrous or alloyed metals are handled better by not permitting flashing to occur. Slower soaking heat of the plain butt weld can be used to favor metallurgical considerations and also permit adjustment of the degree of heat in each of the materials by spacing of the clamps relative to the joint. High-carbon or tool-steel drills, when welded to low-carbon shanks, represent a case where differential heating control is obtained by the manner of clamping. Because of their short plastic range, copper and aluminum butt welds require a machine that will provide a constant pressure on the joint with means to permit the materials to upset together freely as they soften from heat. Special arrangements can be made for suitable welding cycles to accomplish welds between aluminum and copper and other dissimilar combinations.

Butt- and flash-welding equipment is essentially made up of suitable clamping dies to hold and provide contact to the parts, a low-potential high-current welding transformer, a switching arrangement to close and open the welding circuit, a rugged frame with slides or bearings to provide for motion of the moving platen, and a mechanical or hydraulic source of power to move the work parts together under suitable welding conditions. Bars, rods, or compact sectioned pieces are readily handled on the many sizes of standard-design machine. Practicability of making long flash welds on irregularly shaped sheet-metal parts, in some cases exceeding 100 lin in., has been demonstrated in recent years and has opened an extensive field for this class of work. This equipment by nature requires special designs. In general, flash welders are made fully automatic.

CONCLUSION

In conclusion, the following suggestions are offered:

(1) For the present, take advantage of the consultation services offered by the larger builders of resistance welders. It is an exception nowadays when a welding problem is rejected as impossible of accomplishment.

(2) Investigate the newer alloys for welder dies.

(3) Try to incorporate the more dependable welding preparations into the parts, reducing the skill required of operator.

(4) Consider possibilities of welding two assemblies at one time or application of dial feeds to automatic welders.

(5) Look upon the welding machine as a machine-tool investment and procure versatile automatic types, avoiding getting just enough of a machine to do some particular short-lived job.

SYNCHRONIZATION OF CURRENT and Pressure in Spot Welding

By J. S. WILLIAMS†

I. INTRODUCTION

IT HAS only been in recent years that resistance welding has become a major tool in the fabrication of sheet metal parts. Nowadays, however, resistance welding is of such importance that there is hardly any manufacturing concern fabricating sheet metals that does not employ resistance welding in one type or another. Because of the extremely rapid growth of resistance welding, some of the details have necessarily been overlooked to a lesser or greater extent. For example, all people dealing with spot welding, may not fully realize that the proper synchronization of current and pressure are of importance.

No doubt, welding engineers from time to time, have wondered as to the synchronization of the pressure dwell and current timing relationship and have encountered difficulty in obtaining concrete data as to the actual conditions existing in their particular machine without the aid of expensive or complicated instruments.

It is the purpose of this paper to present some data that have been collected in the laboratories of our Company, pertaining to the effect of certain conditions which exist during the welding cycle on the microstructure and physical properties of the resultant welds.

Briefly stating the general spot welding theory, two sheets to be welded are placed between electrodes, the electrodes are brought together on each side of the sheets to be welded and pressure is applied to the electrodes which press the sheets together. While the pressure is applied, a high current is passed through the sheets, being conducted by the same electrodes which apply the pressure. The current flow is maintained briefly which brings the temperature of the interfaces of the metals to a welding condition, when, the applied pressure forges the sheets together, the crystals of the two sheets intermingling and recrystallizing across the interfaces, thereby welding the two sheets together.

There are many devices and auxiliary equipment which allow the current to come on after sufficient pressure has been applied, maintain the current flow for a predetermined period and allow the current to be cut off before the pressure has been removed.

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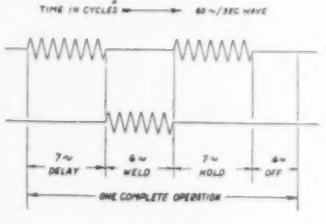


Fig. 1

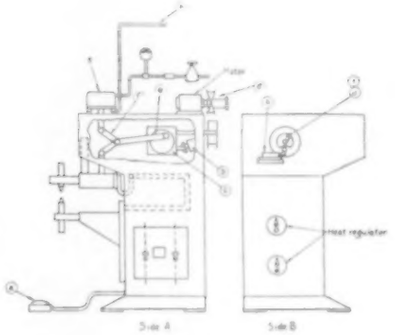


Fig. 2

In most air operated machines, an air switch closes an auxiliary circuit after sufficient air pressure has been built up in the electrode piston chamber. The auxiliary switch may either operate a magnetic contactor or an electronic control, which in turn energizes the welding transformer. There are also combinations of relays and tube controls with air operated machines.

In the mechanical operated welders there are cam mechanisms either connected directly or independently of the electrode lift devices. The mechanical cams open and close auxiliary circuits which energize a magnetic contactor or electronic control.

All these timing devices, whether they are manually operated switches, relay controlled circuits or electronic tube controls must be originally operated or started by direct connection to the welder mechanism.

There is very little indication to the operator that the current is on before full pressure is applied or lingering after the pressure is removed.

In most machines, there is a definite possibility of variation in the time relationship between the pressure cycle and current cycle. This difficulty is greatly aggravated in production or high speed welders where the operation is continuous and rapid.

A graphical welding cycle of a continuous operation welder is shown in Fig. 1.

The time in cycles progresses as indicated by the arrow and is based on an alternating current wave of 60 cycles per second.

This particular weld cycle consisted of:

1. The delay—7 cycles or 0.1167 seconds. The electrodes have made contact with the work and the pressure is applied.
2. The weld time—6 cycles or 0.100 seconds. The welding current is applied to the work.
3. The hold time—7 cycles or 0.1167 seconds. The welding current has been discontinued, the pressure remaining on.
4. The off time—4 cycles or 0.0666 seconds. The electrodes are opening and closing.

The complete weld cycle consumed 24 cycles or 0.400

seconds when the machine was operated at a speed to 150 spots per minute.

II. TEST EQUIPMENT

The experimental equipment consisted of a 100 kva. synchromatic press welder. The essential features are shown in Fig. 2. The machine is entirely automatic, the moving members being driven by a 3-phase motor with variable speed drive.

Closing the pedal switch (*a*) energizes a solenoid (*b*) which engages a clutch (*c*) which drives the welder mechanism through one complete operation at a constant speed determined by the adjustment of the variable speed drive (*d*). The clutch gearing is direct connected to an eccentric disk (*e*) to which is attached an arm operating a toggle mechanism (*f*) which lifts and lowers the upper electrode carriage between guides.

In operation the disk and toggle arrangement allows the upper electrode to travel rapidly from open to closed position with a minimum of impact and when the toggle is straight the air pressure in the head (*g*) exerts a force on the electrode in addition to the weight of the electrode and carriage. A regulated air line (*h*) attached to the

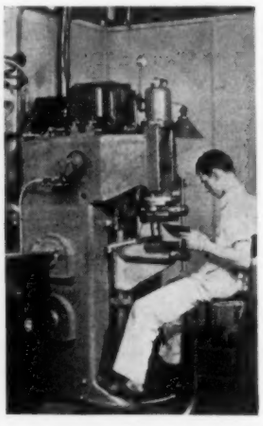


Fig. 3

pressure head under the piston makes possible the application of a counter pressure to the piston. Thus, very light pressures may be obtained or by regulating the upper and lower pressures the friction and dead weight of the electrode carriage may be overcome. Connected to the clutch gearing is the timing cam shaft with two sets of fan cams (*i* and *j*) which operate limit switches (*k*). One switch is connected to the line contactor solenoid and the other energizes an Electronic control firing circuit. The two timing cams operate at a constant speed in conjunction with the welder mechanism. The machine may, therefore, be used with either a mechanical current timer (the timing being determined by the spacing of the fan cams and machine speed), or with Electronic control which permits synchronous and accurate current flow of from 1 to 14 cycles.

Current values are regulated by tapped turns on the welding transformer and 2 to 1 step down transformer is connected in the line giving two line voltages with a total of 44 points of current regulation.

Electrode holders and welder transformers are water cooled.

A photograph of the welder and equipment is shown in Fig. 3.

The length of time the pressure is applied, depends on the machine speed and the electrode spacing for a given

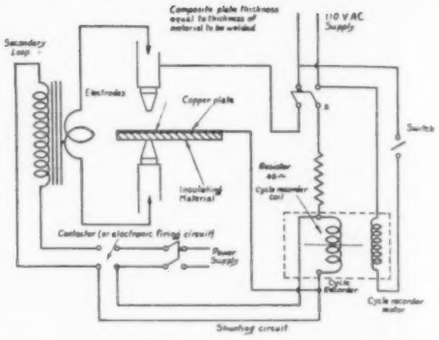


Fig. 4—Schematic Diagram of Pressure Timing—Current Timing Synchronizer

thickness of material to be welded. The length of time of the current dwell and its position with respect to the pressure is determined by the machine speed and the fan cam adjustment.

To aid in positively identifying the various timing phases during the weld cycle a circuit was devised in which a cycle recorder was incorporated. The arrangement of the cycle recorder and auxiliary electrical circuits are shown in Fig. 4.

To obtain a graphical record of the pressure and current relationship the welder was operated without voltage or with the power lines open. The connections were made as shown in Fig. 4 and the pedal switch closed. The electrodes come together on the composite sheet, the sheet being the thickness of the two pieces to be welded. This completes the cycle recorder circuit and the timing is recorded on the rapidly moving paper tape by the frequency responsive vibrating reed. When the contactor in the supply line is "pulled in" the cycle recorder coil is shunted, leaving a blank space on the tape. When the contactor opens again the current passes through the responsive coil and indicates the final pressure or holding time.

A typical graph is shown in Fig. 5.

When the cycle recorder is connected in the secondary of a current transformer in power lines and a weld is made, a graphical record of the current flow timing is obtained. Figure 6 shows the length of current dwell of a spot weld. To obtain a graphical record when using the electronic timer, the shorting leads are connected across the firing circuit of the electronic control.

In Fig. 7 is shown two curves giving the electrode spacing and pressure application as a function of the electrode spacing in the open position.

In Fig. 8 is shown the electrode spacing and piston lift with respect to time for one complete welder operation when using a given electrode spacing and machine speed of 52.8 operations per minute.

The effect of the distance between the electrodes in the open position on the length of the time of pressure application is illustrated in Table 1. Note that the length of time the pressure is applied is a direct function

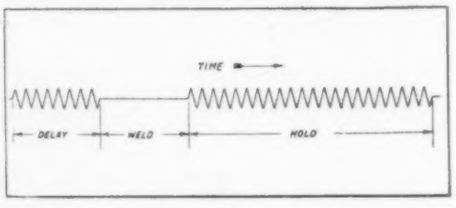


Fig. 5

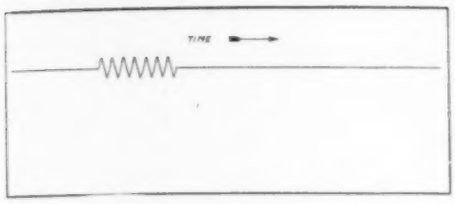


Fig. 6

of the spacing of the electrodes. The length of current dwell, however, is independent of this, and can be regulated by adjusting the fan cams.

Table 1—Electrode Spacing *Vs.* Time Constants Using Given Timing Cam Setting

Record No.	Electrode Spacing	Cycle Timing Delay	Weld Time	Hold Time	Off Time	Total
A	50 mm.	3	7	18	40	68
B	46 mm.	5	7	20	35	67
C	40 mm.	7	7	23	31	68

Welding speed—52.8 spots per minute.

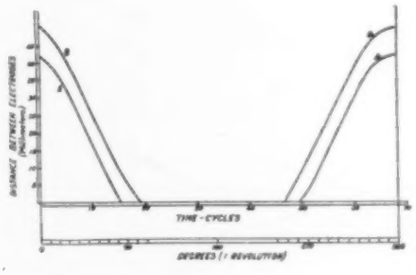


Fig. 7—Pressure-Space Curves for Two Different Electrode Spacings

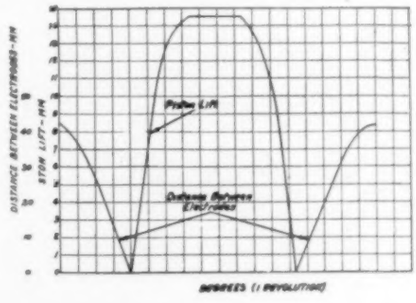


Fig. 8—Electrode Spacing and Piston Lift for One Complete Welder Operation

This is further illustrated by the cycle recorder graphs shown in Fig. 9.

From these graphs it can be seen that it is quite possible, by improper adjustment of the fan cam controlling the current dwell, to have the current either come on ahead of the pressure or remain on after the pressure has been released.

Table 2 shows the variation that can be obtained in the timing constants when the spacing of the current timer cams is changed.

Table 2

Cam Setting or Record No.	Delay	Cycles Weld Time	Hold Time	Off Time	Total
A	5	18	10	37	70
B	5	14	14	37	70
C	5	10	18	37	70
D	5	6	22	37	70
E	5	3	25	37	70

Welding speed—52.8 spots per minute.

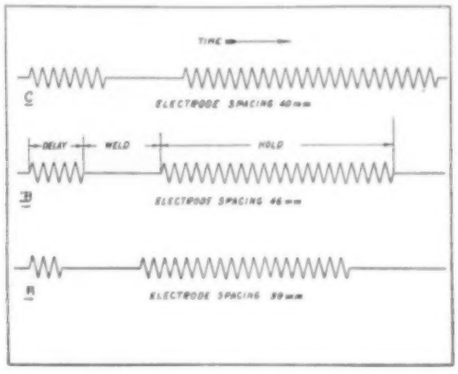


Fig. 9—Electrode Spacing Variation with Current Time-Pressure Relationship

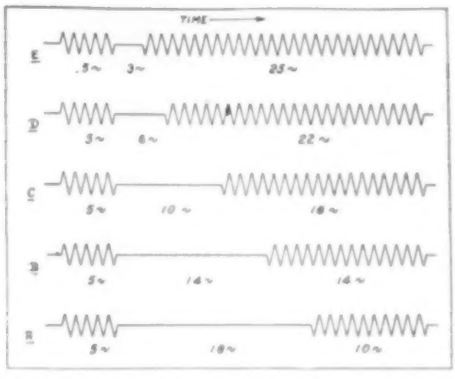


Fig. 10

The graphical records illustrating this are shown in Fig. 10.

It will be seen that the graphs indicate clearly the direction in which the fan cams must be rotated to position the current dwell favorably within the pressure cycle.

There are many factors which may alter the timing relation between the pressure and current. Among these are: inaccurately calibrated air pressure switches, belt slippage, loose gearing, lagging in electrical devices, etc.; rarely any of these can be readily identified by the welding operator. However, they tend to produce inconsistent welds, cause excessive electrode deterioration, result in a high percentage of rejections and make difficult the production of quality welds.

The synchronizing circuit described, makes possible the accurate setting or adjusting of the welding current with respect to the application of pressure and provides a flexible means for the periodic checking of welding conditions. The connections can be easily and quickly made and it is believed that with slight variations, the device may be adapted to any type of welder.

III. RESULTS

To determine the influence of varying the pressure and current dwell on the microstructure and physical properties of the weld, the following experiments were carried out:

In all of these welding tests the following materials and conditions were adhered to unless otherwise noted:

Material welded—cold-rolled steel—0.038 inch thick

Electrodes—$^1/_8$ inch diam. face, Mallory 3

Material hardness—45 to 50 Rockwell *B*

The welding current and applied pressure were held constant.

Part A

Effect of varying the position of the current dwell within the pressure cycle.

Item 1.—Current on before full pressure was applied.

The timing cams were arranged so that the weld current was on slightly before full pressure was applied to the work. The electrode spacing was 50 millimeters. The relationship is shown in Fig. 11.

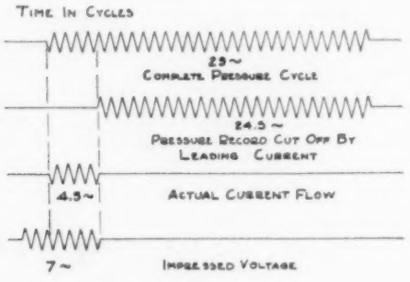


Fig. 11

The recordings show that the cams were set to allow 7 cycles for the weld current. The actual current flow was but 4.5 cycles, indicating that 2.5 cycles of current flow had been cut off because the electrodes were not in contact with the work when the weld voltage was applied. The applied pressure was 18,000 psi on a $^1/_8$ inch diam. flat face electrode. The kva. input was 12.2.

There was no indication that the current was leading the pressure due to the absence of sparking or spitting.

Tensile tests of welds made under these conditions are given in Table 3.

Table 3

Test Experiment Number	Tensile Strength (Lbs.)	Average of 10 Welds
1	556	Hardness on welds—76 Rockwell *B*
2	594	No slugs were pulled on any welds
3	536	

In Fig. 12 is a photomicrograph of a weld made under these conditions.

This photomicrograph indicates a poor bond between the two sheets because the current was not on for a sufficient length of time. The area of the columnar crystals represents the welded area. The weld area is not large enough as compared to the thickness of the two sheets, to have a high strength.

Item 2.—Normal relationship between the pressure dwell and current dwell.

Fig. 12

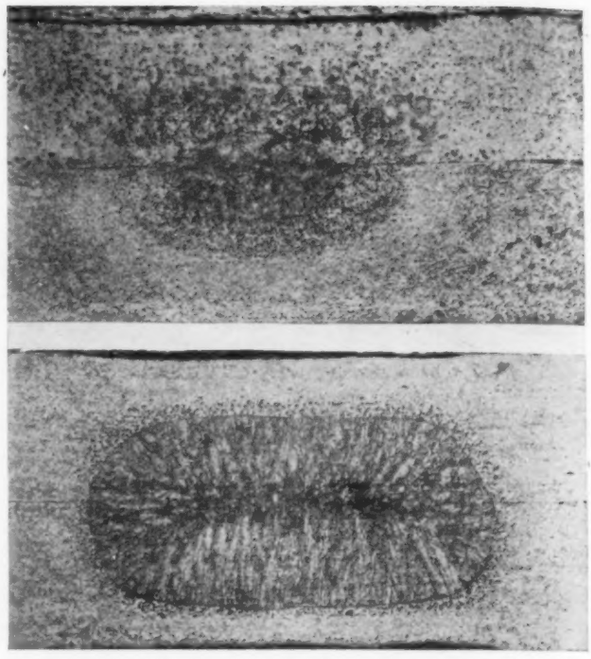


Fig. 14

In this case the current dwell was well within the pressure cycle and the relationship with time is indicated by Fig. 13. The electrode spacing was 44 millimeters and the complete weld cycle is given in Table 4.

Table 4

Delay	5 cycles
Weld time	7 cycles
Hold time	21 cycles
Off time	35 cycles
Total	68 cycles

Results of tensile tests on welds made under the conditions given are tabulated in Table 5.

Table 5

Test Number	Tensile Strength (Lbs.)	Average of 10 Welds
1	886	Hardness on welds—91 Rockwell *B*
2	882	All samples pulled a slug from sheet
3	877	

The applied pressure was 18,000 psi on a $^1/_8$-inch tip diameter and the welder input was 12.2 kva.

In Fig. 14 is shown a photomicrograph of a representative weld made under these conditions.

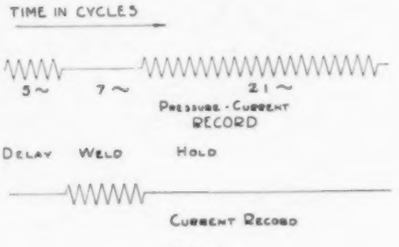


Fig. 13

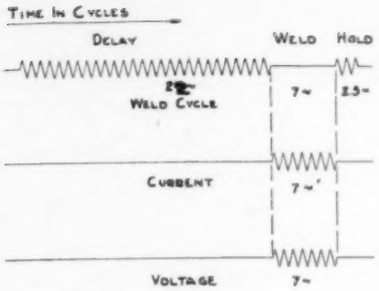


Fig. 15

The elliptical weld area shown is of such size with relation to the thickness of the two sheets that good tensile properties would be expected. This is confirmed by the results shown in Table 5. Note the soundness of the weld, freedom from porosity and the minimum of indentation or "brinelling" from the electrodes.

Item 3.—Current applied near end of pressure cycle.

In this experiment the timing cams were set to give the relationship between the pressure application and the current dwell as shown in Fig. 15. As can be seen, the current is applied on the tail end of the pressure cycle. The time constants being given in Table 6.

Table 6

Delay	22 cycles
Weld time	7 cycles
Hold time	2.5 cycles
Off time	33 cycles
Total	69 cycles
Electrode spacing	42.5 millimeters

In Table 7 are given the average results of tensile tests made on welds under these conditions.

Table 7

Test Number	Tensile Strength (Lbs.)	Average of 10 Welds
1	800	Hardness on welds—80 Rockwell *B*
2	820	7 out of 10 welds pulled slugs
3	766	

In spite of the fact there is little final pressure to forge the hot metal sheets together the tensile strengths of the welds are quite consistent. An examination of the microstructure of a typical weld, however, (Fig. 16) discloses blow-holes and porosity in the recrystallized area.

A possible reason for the porosity may be that the pressure was released while the metal was still in the plastic state and internal stresses or occluded gases which had not been squeezed out caused the formation of "blow-holes."

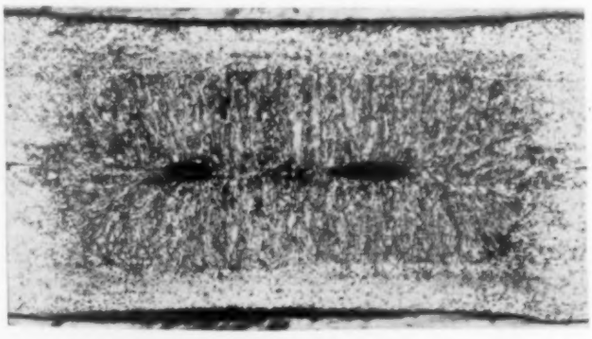


Fig. 16

It was noted that the weld was still at a red heat when the electrode moved away from the weld. This resulted in normalizing or partial annealing of the weld. The hardness is lower than found with normal timing relationship.

The condition just described would be extremely detrimental to the excellent corrosion resistant properties of stainless steel. The relatively slow cooling of the weld from the welding temperature probably would result in the precipitation of carbides.

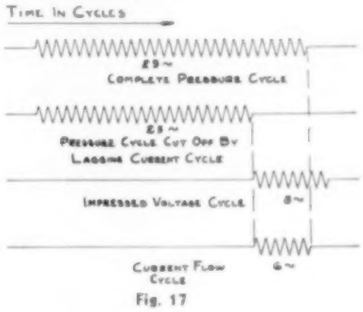


Fig. 17

Item 4.—Current on while the pressure is being released.

In this experiment the electrode spacing was increased to 50 millimeters from the 42.5 millimeters, thus allowing the pressure to be released while the welding current remained on.

The recordings of the timing relationship are shown in Fig. 17.

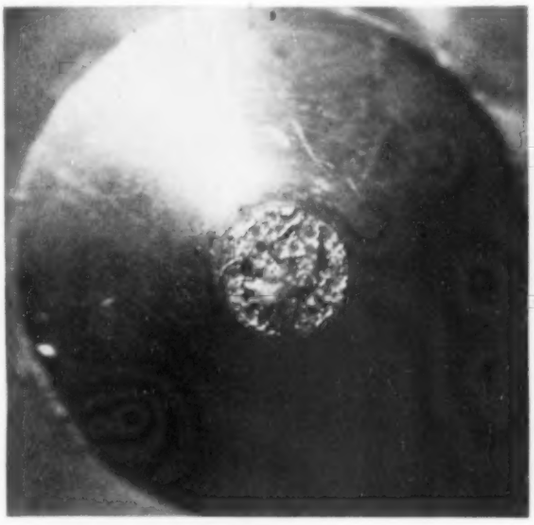


Fig. 18

Four records are shown. Each graph indicates the length of time of a particular factor. The first graph shows the complete pressure cycle; the second the moment in the pressure cycle at which the current starts to flow; the third is a record of the voltage impressed on the welding transformer; the fourth the length of time of the current dwell.

These recordings show the current tends to extend 2 cycles past the length of the pressure application. The voltage impressed on the transformer 8 cycles, the current flowing through the weld was 6 cycles.

Tensile properties of representative welds made under these conditions are given in Table 8.

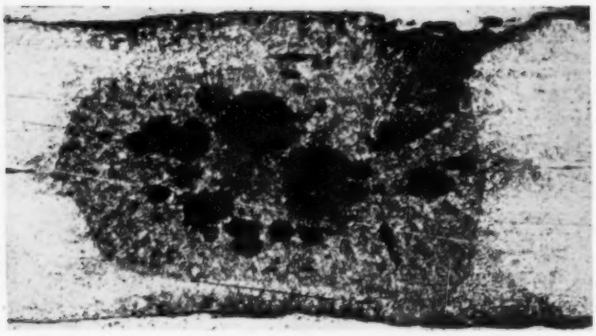


Fig. 19

Table 8

Test Number	Tensile Strength (Lbs.)	Average of 10 Welds
1	228	No slugs pulled
2	316	Welds contain large voids
3	558	

The welding operation was characterized by spitting and blowing of the weld-metal when the electrodes were opened. The welded metal adhered to the electrodes causing rapid deterioration and extremely poor welds.

Figure 18 is a photograph showing the condition of the welding face of an electrode which "broke" the welding circuit because the pressure was released before the current was cut off. Note the alloying that has occurred due to melting of the cold-rolled steel and the electrode face by the high temperature of the arc that was drawn between the electrode and sheets.

The inconsistency of the welds obtained in this experiment is indicated by the low and scattered tensile properties.

Figure 19 is a photomicrograph showing the extremely porous or "blowy" structure obtained.

Experiments similar to those just described were repeated using brass (70 Cu–30 Zn) as the material to be welded. The only change in conditions was that the pressure was reduced to 10,000 psi, and the kva. input increased to 17.7.

The results were identical to those obtained with cold-rolled steel. In general, however, the results were more pronounced than with cold-rolled steel. This was true of the physical properties as well as the microstructure.

IV. CONCLUSIONS

It is believed that the results of the foregoing experiments indicate conclusively the necessity of properly synchronizing the current dwelling time with relation to the pressure application period. If these conditions are not properly established and maintained the resultant welds will have low and inconsistent physical properties The microstructure will reveal a porous and only partially recrystallized area.

The results demonstrate the accuracy to which the current dwell can be set and maintained with respect to the applied pressure by making use of a simple synchronization circuit in conjunction with a cycle recorder.

Service to the Farmer

Shops Use Ingenious Methods to Promote Hard-Facing

By R. K. KENNEDY†

A NUMBER of welding shops have recently adopted an ingenious and profitable method for obtaining increase hard-facing business. After the fall plowing season is over, trucks are sent throughout the community to collect the farmers' plowshares. The shares are brought into the shop, ground, hard-facing metal is welded onto the wearing edges, and they are sharpened. A coating of grease is applied to prevent rusting of the steel. The welding operator then stores them in his shop, and the plowshares are all ready for spring plowing. When the farmers are ready to break the ground at the end of winter, they come in and get the shares. Usually no charge is made for storage and the only cost to the farmer is that of hard-facing, which is quite reasonable.

The benefits of this service are two-fold. Farmers are relieved of the storage problem, and they know that when they request delivery, the implements will be received in the best possible condition, ready for use and assured of long service life. The welding shops appreciate the success of the plan too, for they have ample opportunity to exercise every care in doing a fine welding job, and thereby increase the confidence of their customers in their work. In addition, they are relieved of the last-minute rush just before the spring plowing season begins.

Farmers in the areas served by shops which have inaugurated this service seem well pleased with it. This is borne out by the fact that several shops handled over 600 plowshares last winter, while one shop which has been giving this service for several years hard-faced and stored over 1250 shares in one season.

Hard-facing is done by the oxyacetylene process. In hard-facing plowshares the hard-facing material is flowed onto the drawn-out, sharpened steel share under the oxyacetylene flame. The share is resharpened and is ready for a service life of from 4 to 6 times as long as that of a plain steel share.

† Haynes Stellite Company, General Publicity Department, New York, N. Y.

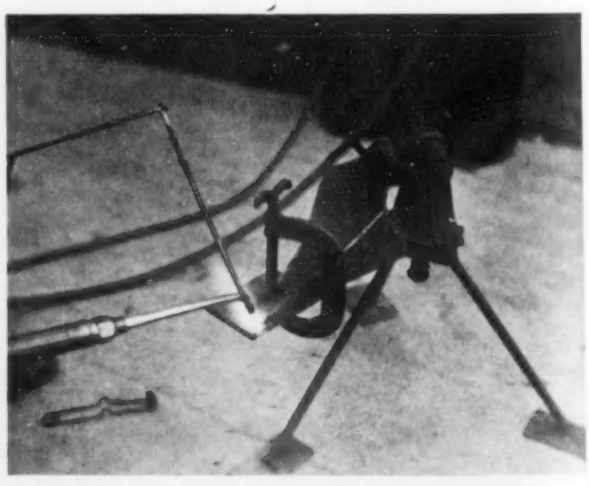


Fig. 1—Hard-Facing of Plowshares During the Winter Months Offers a Readily Available Source of Profit for Every Blacksmith Welder or Welding Operator

INSPECTION METHOD USED in Manufacture of U-69 and U-70 Pressure Vessels

THE Committee recommends the plan of trepanning plugs from welded seams and the examination of those plugs as a means of inspecting and determining the soundness of welding as applied in the construction of pressure vessels built in accordance with paragraphs U-69 and U-70 of the A. S. M. E. Unfired Pressure Vessel Code.

Where X-ray equipment is available it is recommended that approval be given for the use of radiographic examination in place of plugs removed.

The following are suggested specifications covering the application of the trepanned plug method:

SELECTION OF LOCATION AND NUMBER OF PLUGS REMOVED

An authorized inspector shall have the right at any time to call for and witness the removal of one or more plugs from welded seams. The inspector shall call for and witness the removal of at least one plug from each vessel. Where the vessel contains more than fifty and less than 100 feet of welded seam, two plugs shall be removed. For vessels containing 100 feet of welded seam or over, three plugs shall be removed. Where more than one process of technique of welding has been employed on a single vessel, at least one plug shall be removed for each process or technique employed.

SIZE OF PLUGS AND THEIR REMOVAL

Plugs should be removed in the form of a cylinder, the diameter of which shall be at least equal to the width of the weld. Removal may be either with a trepanning tool or accurately guided cutting torch.

EXAMINATION OF PLUGS AND THEIR APPROVAL OR REJECTION

Each plug shall be sectioned in such a manner as to reveal the full cross section of the welded joint, the two cross-sectional surfaces of the specimen plug shall be polished to bright, smooth surfaces. This may be accomplished by grinding or filing and then polishing with emory cloth of which the 00 grade should be finally used. The specimen shall then be etched in a boiling solution of equal parts of hydrochloric acid and water for a sufficient period of time to reveal any lack of soundness that may exist.

Defects as respects soundness are defined as gas pockets, slag inclusion, lack of fusion and cracks no one of which may exceed $^1/_8$ inch in greatest dimension. Lack of soundness shall be evaluated by the total depth of all "zones of defects." Measurements of such depth should be made on a line or plane parallel to the throat of the weld. A "zone of defect" is defined as the area within two lines perpendicular to the throat of the weld and tangent to any one defect or any group of defects

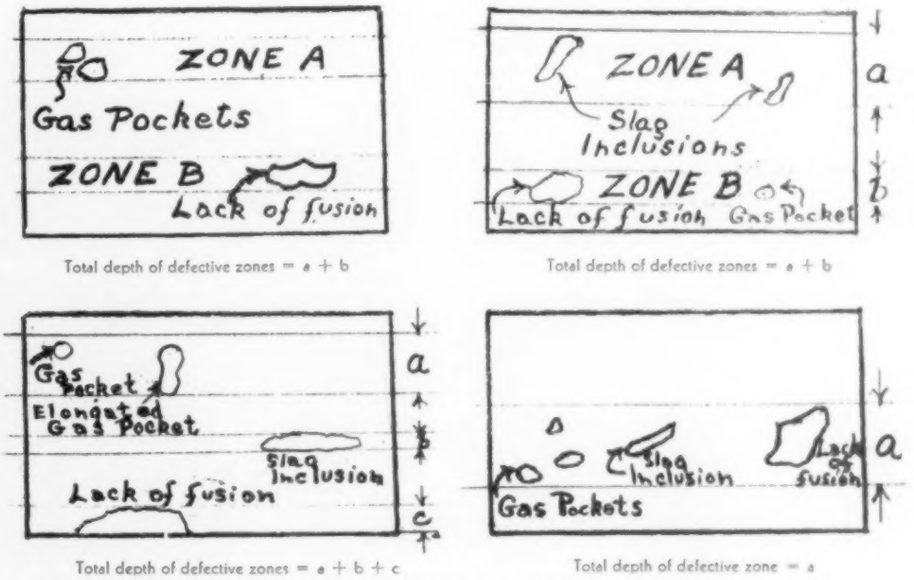


Fig. 1—The Above Sketches Illustrate Typical Views of the Face of Fractures in Broken Specimens of Any Type

D = Diameter of plug shall be such as to fit snugly into the hole and to provide a suitable preparation for welding

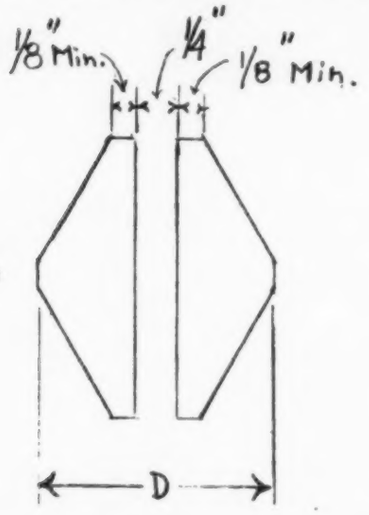


Fig. 2

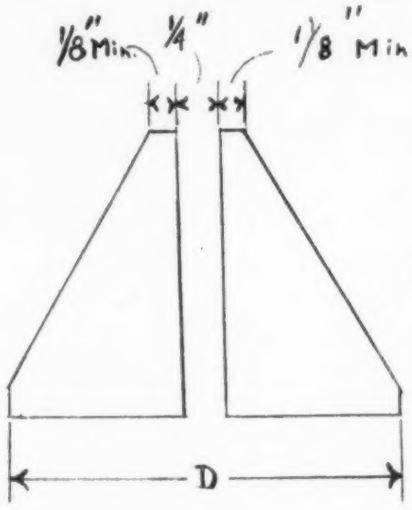


Fig. 3

whose depths are overlapping. Illustrations of typical zones of defects and the total depth of such zones are given in Fig. 1.

The permissible total depth of all zones of defects shall not exceed 20% of the specified weld throat dimensions for longitudinal joints or 30% for girth joints except that for plates $^1/_4$ inch thick or less, the maximum depth shall not exceed $^1/_{16}$ inch.

Where the total zone of defects exceeds the foregoing limits, two additional plugs shall be removed as directed by the inspector from the same vessel from which the rejected plug was taken. If either of these plugs show more than the specified limit, the vessel shall be rejected. If both plugs are within the limits specified, the vessel may be accepted.

FILLING HOLES MADE BY THE REMOVAL OF PLUGS

Holes formed by trepanning the plugs shall be filled by the insertion and welding in of special plugs designed in accordance with the attached sketches. Design Fig. 2 adapted for welding from both sides shall be used wherever it is practicable to weld from both sides. Design Fig. 3 shall be used when access is possible only from one side. The diameter of the plug shall be such as to make a snug fit into the hole to be filled. Each layer of weld-metal deposited shall be thoroughly peened to reduce residual welding stresses. The weld-metal and heat-affected zone shall be thoroughly peened after completion of the welding. The $^1/_4$-inch hole in the center of the plug shall be closed by threading the opening and inserting a pipe plug which may be seal welded if desired.

Where gas welding is employed the area surrounding the plug shall be preheated prior to its welding.

If and when satisfactory data are presented that holes may be safely left in a welded joint, provision should be made for closing trepanned holes in welded joints by tapping the hole and inserting a straight threaded snugly fitting plug, the outer end of which is slightly beveled and then seal welded for tightness.

Committee on Inspection Method in Manufacture of U-69 and U-70 Pressure Vessels:

H. E. Rockefeller, *Chairman*	E. R. Fish	L. A. Sheldon
H. L. Babcock	L. S. Morse	R. K. Strayer
H. C. Boardman	C. W. Obert	R. W. Thomas
A. J. Deacon	F. G. Sherbondy	H. W. Torrance

Flywheel Clutch Face Rebuilt

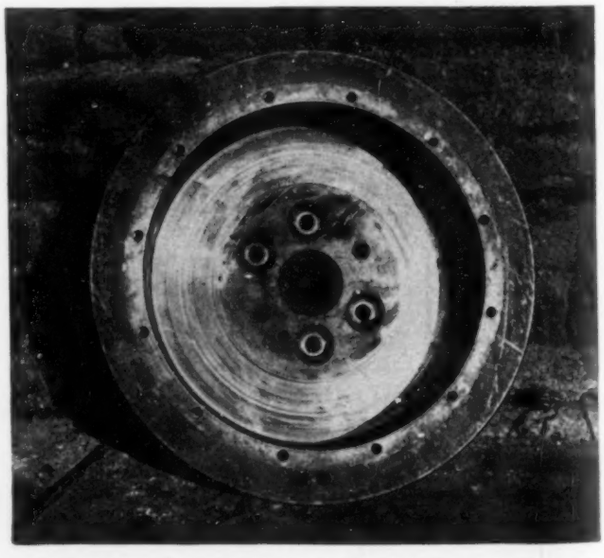
By GEORGE SYKES†

AN interesting instance of the use of bronze-welding rod for the resurfacing of a bus flywheel recently was reported from the South. The accompanying photograph shows the test wheel as it came out of the bus. The face of the wheel that is seen is the clutch face, which undergoes considerable wear.

This clutch face was built up with about 3 lb. of wear-resisting bronze-welding rod. Altogether, 2 hr. were required for the rebuilding job, 30 min. for the welding operation, and $1^1/_2$ hr. for machining. The cost for a new part similar to this would have been about $20, while the reclamation charges were under $4.

From latest reports, this rebuilt clutch face has now run 25,000 miles and is said to be as good as new. While the regular flywheel lasts about 100,000 miles, so that no actual comparison has as yet been made, it is the feeling at the maintenance shop that the rebuilt flywheel will last as long as, if not longer than a new wheel.

†General Publicity Department, Union Carbide Company.



Worn Clutch Face from Bus Flywheel Before Resurfacing with Bronze-Welding Rod

PREHEATING AND WELDING

Locomotive Cylinders

By F. W. GRANEMAN†

THE two photographs reproduced in Figs. 1 and 2, and the sketches, Figs. 3 and 4, are shown to illustrate the preheating furnace and methods employed in salvaging two mating locomotive cylinders by oxyacetylene welding for a western railroad.

Due to the location of the cracks, it was necessary to remove these cylinders and turn them bottom side up. In order to get at the cracks, two "door" openings were drilled out of one cylinder, and the door covers are shown in Fig. 1, leaning against the scaffold on the left-hand side, welded to pieces of $1^1/_4$-inch pipe. The cracks in the valve chamber were welded and heavily reinforced to insure against checking again. The "doors" were then placed back in position by means of the pipe handles, and welded in when preheated by the cylinder temperature.

The furnace was made of firebrick, and cemented with wet asbestos to prevent the heat from escaping. The roof was made of $^1/_4$-inch sheet asbestos. Charcoal briquets were packed around the cylinder to a depth of two feet and the fire was started about 4 P.M. the previous day. Additional fuel was added at midnight and again at 7 A.M. By 9 o'clock, the cylinder was red-hot, and ready for welding.

The welding time was about six hours, using four operators, who alternated frequently due to the intense heat. Standard welding torches were used, with special tips made of copper tubing about six feet long, swaged down on the end to size equivalent to a welding tip with orifice 0.1610 inch diameter. The welding rods used were $^1/_4$-inch cast-iron rods welded to the end of a $^1/_2$-inch pipe in clusters of three and four rods, two and three lengths being welded together.

These welding rods and tips are shown in Figs. 1 and 2, leaning against the scaffold.

A long spoon was used for baling in the flux, and this particular job required 9 pounds of flux.

After the welding was completed, the holes through which the welding was done were closed and the cylinder was not removed until cold, which required about three days.

This job required 165 pounds of $^1/_4$-inch cast-iron rods, 9 pounds of flux, 965 cubic feet of oxygen, 965 cubic feet of acetylene and 925 pounds of charcoal briquets.

During the past seven years over 200 cylinders have been welded on this railroad. For about half of these cylinders it was necessary to remove them from the engine, due to the location of the cracks. So far only four of these welded cylinders have failed, and these failed after having been in service for twelve months.

The average total cost of reclaiming cylinders on this railroad by oxyacetylene welding is about $75 each, exclusive of course of other costs, such as stripping down, removing from engine and replacing when finished.

† Supervisor, AED Minneapolis District, Air Reduction Sales Company.

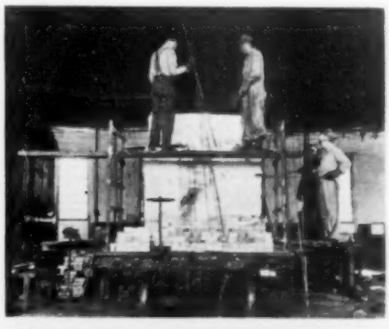


Fig. 1—Welding Locomotive Cylinder While Preheated in Firebrick Furnace Built on Flat Car. Note "Doors" Removed for Access at Left, Welded to $1^1/_4$-Inch Pipe

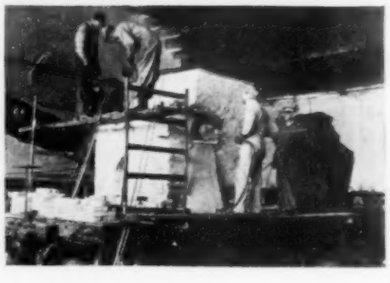


Fig. 2—Welding Locomotive Cylinder in Preheating Furnace, Mate to Cylinder Shown on Flat Car at Rear

Fig. 3—Right Side Cylinder Showing Where "Doors" Were Cut to Give Access to Cracks in Piston Valve Chamber

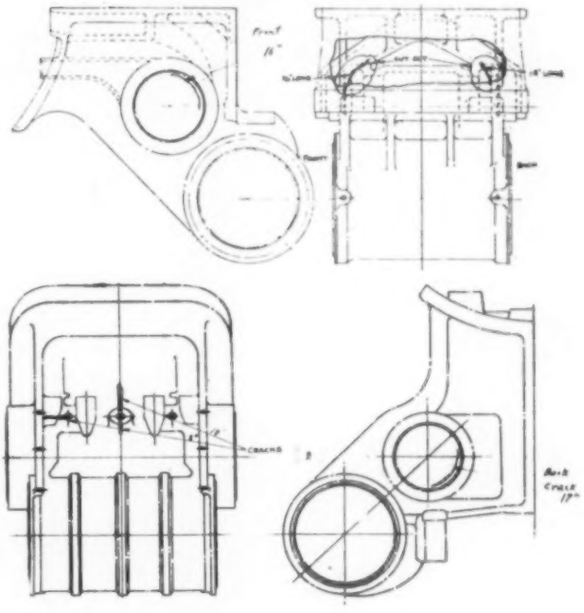


Fig. 4—Showing Cracks in Left Side Cylinder Piston Valve Chamber. Accessible for Welding from the Outside

TENTATIVE RULES FOR FUSION

Welding Steam, Oil or Air Piping in Marine Construction

Published for the Purpose of Eliciting Comments, Criticisms and Suggestions

These Rules apply to piping for working pressures in excess of 100 lb. per sq. in. They do not apply to piping for water and oil at normal temperatures. These Rules are not to be construed as prohibiting pressure thermit and electrical-resistance welding.

1. *Qualification of Welding Processes.*—(*a*) Before a contractor may weld piping under these rules a representative of the Enforcement Authority will visit the part of his works in which welding is done for the purpose of inspecting the welding plant to make sure he has a suitable equipment and to witness the series of tests outlined in Section (*b*) of this paragraph.

(*b*) The tests for qualifying a welding process shall be either those embodied in the Tentative Rules for the Qualification of Welding Processes and Testing of Welding Operators or those given in Appendix I which follows, as prescribed by the Enforcement Authority.

2. *Rules for Qualification of Welding Operators.*—The Rules for Qualification of Welding Operators shall be those given in the A. W. S. Tentative Rules for the Qualification of Welding Processes and Testing of Welding Operators or those given in Appendix II which follows, as prescribed by the Enforcement Authority.

3. *Design of Piping.*—The piping shall be designed to avoid excessive strains due to expansion and the working of the ship.

4. *Layout and Dimensions of Piping.*—Prints showing the layout and dimensions of the piping shall be forwarded to the Enforcement Authority for approval. Sections of pipes shall be welded in the shop as far as practicable. All welded joints made on shipboard shall be in positions where there is sufficient space to allow proper access for the welding, and such welds shall be definitely indicated on the plans by the use of appropriate AMERICAN WELDING SOCIETY weld symbols or details of the welds. A sufficient number of detachable joints shall be used in installing the piping to facilitate removals. Valves and other fittings may have either flanged or welded connections to the pipes but flanged joints shall be used where necessary to facilitate overhauling of machinery or the valves themselves.

5. *Types of Welded Joints to Be Used.*—Butt joints shall be used for pipes over 2 inches nominal pipe size and shall be either double welded or welded with a backing-up strip on the inside of the pipe. Pipes not over 2 inches nominal pipe size may be connected by ferrules fitted over the ends of the pipe and attached by circumferential fillet welds to the pipe, or by using bell and spigot joints and uniting the end of the bell to the outside of the pipe by a circumferential fillet weld.

6. *Stress Relieving of Plain Carbon Steels.*—(*a*) All welded joints over 2 inches nominal pipe size shall be stress relieved.

(*b*) The welds of plain carbon steel pipe and adjacent piping for a length of six times the wall thickness of the pipe shall be heated uniformly to at least 1150 F. and up to 1250 F. The weld and adjacent piping shall be brought slowly up to within the specified temperature range and held at that temperature for a period of time proportioned on the basis of at least one hour per inch of pipe wall thickness and shall be allowed to cool slowly in a still atmosphere. There shall be no cooling other than by the still air around the weld and adjacent parts being stress relieved in order to assure a gradual fall of temperature along the length of the pipe. For alloy steel piping the stress relieving and/or heat treatment shall be done in a way that shall be demonstrated under Par. 1 to be satisfactory. Where piping is welded to valves it may be impossible to heat the part next the valve to a uniform temperature for a length of six times the wall thickness without overheating the valve. In such a case the heated zone shall extend at least 2 inches on the valve side from the line of fusion of the joint and the temperature shall be allowed to diminish gradually toward the valve.

(*c*) All complicated connections shall be stress relieved as a whole in a furnace provided for the purpose before being taken on shipboard.

(*d*) The piping shall be so designed that it will be free to expand in a longitudinal direction when the joints are stress relieved, thus eliminating stresses that might result through contraction of the piping after the stress relieving.

7. *Radiographic and Other Tests.*—All welded joints shall be tested either by radiography or by using a paramagnetic powder dusted over the area to make sure that there are no cracks or other defects. Should the quality of a joint be questioned by a representative of the Enforcement Authority, the weld shall be cut out and the joint rewelded.

8. *Stamping of Work.*—Each welding operator shall be required to stamp his work with his identification symbol.

9. *Hydrostatic Tests.*—Hydrostatic tests shall be made on the piping at three times the maximum pressure to which the piping will be subjected in service.

QUALIFICATION OF WELDING PROCESSES FOR FUSION WELDING OF MARINE PIPING

1. *General Requirements.*—Before any qualification tests of welding operators are conducted, each manufacturer shall prepare for test the types of test samples hereinafter specified for the purpose of qualifying his welding process.

2. *Manufacturer's Record of Process.*—A complete record of the manufacturer's process shall be made in the form shown by Fig. 7 to establish the definite limits of all essential variables involved. The manufacturer shall conduct all welding in accordance with the requirements of his process record, after his process of welding has been approved.

3. *Number, Type and Size of Test Welds.*—The test specimens shall be prepared in accordance with the requirements of Fig. 2. One test specimen shall be prepared for each process and welding position which will be encountered. One test weld shall be made in the minimum pipe wall thickness and one in the maximum pipe wall thickness to be used, except that the thickness need not exceed $1^1/_2$ inches.

4. *Base Metal and Its Preparation.*—The base material and its preparation for welding shall comply with the manufacturer's process record. For all test welds, the dimensions of the base material shall be such as to provide sufficient material for the test specimens called for hereinafter.

5. *Positions of Test Welds.*—The positions of pipe welding will be classified as follows: (*a*) horizontal rolled, (*b*) horizontal fixed and (*c*) vertical fixed. If a process is investigated for the horizontal fixed position, it need not be repeated for the horizontal rolled position, provided that the same welding process is employed, as defined by the manufacturer's process record. For welds representing the horizontal rolled and horizontal fixed positions, the axis of the pipe shall be approximately horizontal. For test welds representing the vertical fixed position, the axis of the pipe shall be approximately vertical. The pipe shall be rotated for the test weld representing the horizontal rolled position, and shall not be rotated for test welds representing the horizontal fixed and the vertical fixed positions.

FIG. 1. MANUFACTURER'S RECORD OF PROCESS

CONTRACTOR'S NAME _____

ADDRESS _____

PROCESS _____ DATE _____

MATERIAL { BASE METAL _____ / FILLER METAL _____

FOR GAS WELDING
TYPE OF FLAME
_____

FOR ARC WELDING
TYPE OF CURRENT
_____
IF D.C., STATE POLARITY
_____

IDENTIFICATION SYMBOLS OF THIS WELD _____

PASS NUMBER	HEAT INPUT DATA			DIAM. OF FILLER METAL	TEMP °F. *	REMARKS

IN ABOVE SPACE INDICATE EDGE PREPARATION AND RELATIVE POSITION OF EACH PASS AS DEPOSITED.

* GIVE DEGREE OF PREHEAT, IF ANY. INDICATE TEMPERATURE OF WELD METAL JUST PRIOR TO THE DEPOSITION OF EACH SUCCEEDING PASS.

CLEANING OF PASSES _____

TREATMENT OF DEFECTS _____

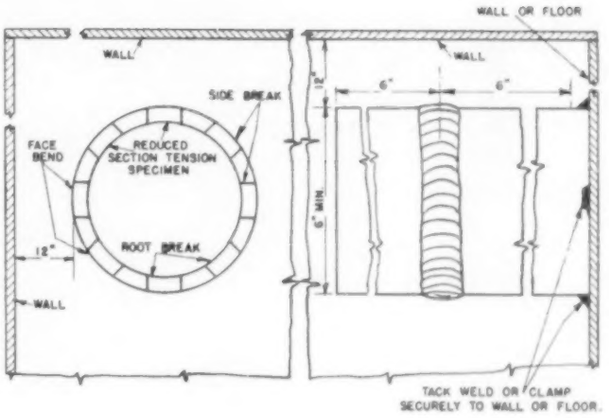
PEENING _____

HEAT TREATMENT AFTER WELDING { TEMP. _____ / TIME _____ / COOLING _____

NAME OF WELDER _____

NAME OF RECORDER _____

FIG. 2. WELDING OF TEST SAMPLES.



POSITIONS OF WELDING
PIPE IN HORIZONTAL FIXED POSITION
PIPE IN VERTICAL FIXED POSITION
PIPE IN HORIZONTAL ROLLED POSITION

NOTES:

1. BREAK EDGES OF BEND SPECIMENS TO A RADIUS OF $\frac{1}{8}$ T MAX.
2. MARK TOP AND FRONT OF PIPE TO INSURE PROPER LOCATION OF SPECIMENS.
3. ALLOW $\frac{1}{4}$" METAL FOR SAW CUTS; $\frac{1}{2}$" FOR TORCH CUTS.

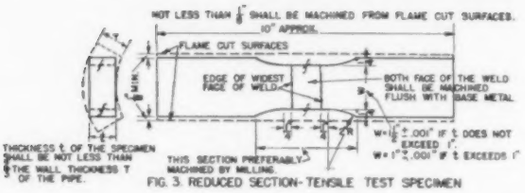
6. *Test Specimens—Number, Type and Preparation.*—The following specimens shall be prepared from each test weld, conforming to the dimensions shown on the applicable figure:

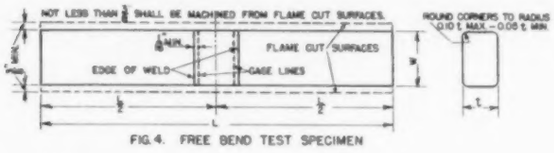
2 Reduced section tensile specimens—Fig. 3
2 Free bend specimens with face in tension—Fig. 4
2 Root break specimens—Fig. 5
2 Side break specimens—Fig. 6

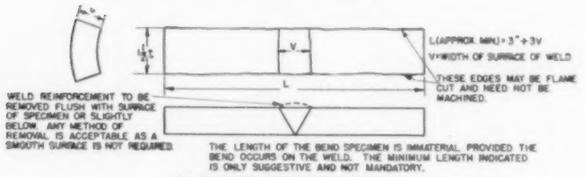
7. *Test Requirements*

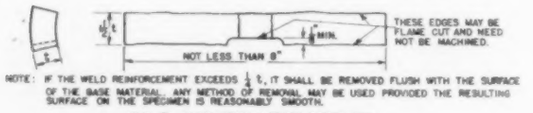
(*a*) *Reduced Section Tensile Specimen.*—The tensile strength of the reduced section tension specimen shall be not less than the minimum tensile strength specified for the pipe.

(*b*) *Face Bend Specimens.*—The specimens shall be bent until failure occurs in the outside fibers of the bend specimen. When a crack is observed in the convex surface of the specimen between the edges, the specimen shall be considered to have failed and the test shall be stopped. Cracks at the corners of the specimen shall not be considered as a failure. The appearance of small defects in the convex surface shall not be considered as a failure if the greatest dimension does not exceed $^1/_{16}$ inch. The performance of the specimen is evaluated by measurement of the outside fiber elongation. The ductility of the free-bend test specimens shall be 20 per cent minimum.


NOT LESS THAN 1/8" SHALL BE MACHINED FROM FLAME CUT SURFACES.
10" APPROX.
FLAME CUT SURFACES
EDGE OF WIDEST FACE OF WELD
BOTH FACE OF THE WELD SHALL BE MACHINED FLUSH WITH BASE METAL
THICKNESS t OF THE SPECIMEN SHALL BE NOT LESS THAN 3/4 THE WALL THICKNESS T OF THE PIPE.
THIS SECTION PREFERABLY MACHINED BY MILLING
FIG. 3. REDUCED SECTION-TENSILE TEST SPECIMEN


NOT LESS THAN 1/8" SHALL BE MACHINED FROM FLAME CUT SURFACES.
ROUND CORNERS TO RADIUS 0.10 t MAX. - 0.05 t MIN.
FLAME CUT SURFACES
EDGE OF WELD
GAGE LINES
FIG. 4. FREE BEND TEST SPECIMEN


L (APPROX. MIN.) = 3" + 3V
V = WIDTH OF SURFACE OF WELD
THESE EDGES MAY BE FLAME CUT AND NEED NOT BE MACHINED.
WELD REINFORCEMENT TO BE REMOVED FLUSH WITH SURFACE OF SPECIMEN OR SLIGHTLY BELOW. ANY METHOD OF REMOVAL IS ACCEPTABLE AS A SMOOTH SURFACE IS NOT REQUIRED.
THE LENGTH OF THE BEND SPECIMEN IS IMMATERIAL PROVIDED THE BEND OCCURS ON THE WELD. THE MINIMUM LENGTH INDICATED IS ONLY SUGGESTIVE AND NOT MANDATORY.
FIG. 5. ROOT BREAK TEST SPECIMEN.


THESE EDGES MAY BE FLAME CUT AND NEED NOT BE MACHINED.
NOT LESS THAN 8"
NOTE: IF THE WELD REINFORCEMENT EXCEEDS 1/4 t, IT SHALL BE REMOVED FLUSH WITH THE SURFACE OF THE BASE MATERIAL. ANY METHOD OF REMOVAL MAY BE USED PROVIDED THE RESULTING SURFACE ON THE SPECIMEN IS REASONABLY SMOOTH.
FIG. 6. SIDE BREAK TEST SPECIMEN.

(*c*) *Nick Break Test Specimens.*—The fracture of the break specimens shall be free from any evidence of lack of fusion or slag inclusions. No more than 6 blowholes per square inch of cross section of the fracture will be permitted.

QUALIFICATION OF FUSION WELDING OPERATORS FOR WELDING MARINE PIPING

1. Before being permitted to perform any work, each manual fusion welding operator shall pass the test required hereinafter. The contractor shall direct and supervise the testing of welding operators and shall bear the expense of conducting these tests. The welding and testing of the specimens shall be witnessed by a duly authorized Inspector.

2. The qualification test described hereinafter is a specially devised test to demonstrate the welding operator's ability and may or may not conform to the requirements for production welding. The practices required in the qualification test shall not be used as a guide for Construction welding; the latter shall be done in accordance with the requirements of the Process Qualification Record. Welding operators qualified under the all position requirements of this test will be considered as qualified to make welds on thin and heavy wall piping.

3. The contractor shall be required to have the welding operator repeat this test when, in the opinion of the Inspector the work indicates a reasonable doubt of the welding operator's ability. In such cases the welding operator shall not be permitted to resume work until he passes the retest.

4. Any welder who has not been employed as a fusion welding operator for a period of three months or more shall, before being permitted to perform construction work, be required to pass the applicable qualification test even though he has previously passed such test.

5. The qualification test shall be conducted with the same equipment, or equipment equivalent thereto in performance and condition, in the opinion of the Enforcement Authority, as was used in the Process Qualification test and is to be used in the actual work.

6. If during the period governed by a qualification test a new brand or make of filler metal (approved by the Enforcement Authority) different from that with which the original process qualification tests were made is to be used, the contractor shall demonstrate that the new filler metal can be successfully used by welding operators who have previously passed qualification test No. 1 with the former filler metal. Should approval for its use be granted, approval and data shall be appended to the contractor's Process approval.

7. The qualification test material shall conform to the materials to be used in the Process approval and in actual work.

8. The filler metal sizes used in these tests shall be those to be used in the Process approval and in actual work for pipe of the same thickness used for the qualification test.

9. Any special treatments, such as preheating or peening shall not be used unless such special treatments were used in the Process approval tests and will be used in the actual work, however, all specimens shall be stress relieved as required in actual work.

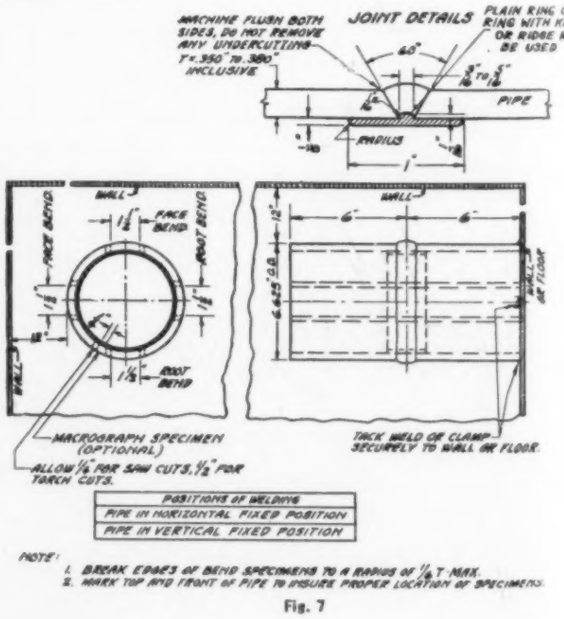
10. All qualification specimens shall be stamped, stenciled or otherwise indelibly marked with the welding operator's identification number, and other applicable marking sufficient to establish the position of welding and type of specimen.

11. The following qualification tests shall be used as directed hereinafter in qualifying fusion welding operators.

12. Welding operators that are to fusion weld pipe in the shop where the pipe may be rolled shall prepare the horizontal specimen of Fig. 7, rolling the specimen while welding. Welding operators that are to fusion weld pipe in all positions and locations shall prepare the horizontal fixed and vertical fixed specimens of Fig. 7 but need not prepare the rolled specimen.

13. Qualification test No. 1 shall be the welding of specimens prepared in accordance with Fig. 7, which after machining or grinding, shall be bent in accordance with the requirements of paragraphs 14 and 15.

14. Specimens for qualification test No. 1 shall be bent in a bending jig having the exact profile shown in Fig. 8. Root bend specimens shall be bent with the root of the weld in tension; face bend specimens with the face in tension.


MACHINE FLUSH BOTH SIDES, DO NOT REMOVE ANY UNDERCUTTING
JOINT DETAILS
PLAIN RING OR RING WITH KNOB OR RIDGE MAY BE USED
PIPE
RADIUS
FACE BEND
ROOT BEND
WALL
MACROGRAPH SPECIMEN (OPTIONAL)
ALLOW 1/8" FOR SAW CUTS, 1/2" FOR TORCH CUTS.
TACK WELD OR CLAMP SECURELY TO WALL OR FLOOR.
POSITIONS OF WELDING
PIPE IN HORIZONTAL FIXED POSITION
PIPE IN VERTICAL FIXED POSITION
NOTE:
1. BREAK EDGES OF BEND SPECIMENS TO A RADIUS OF 1/8 T MAX.
2. MARK TOP AND FRONT OF PIPE TO INSURE PROPER LOCATION OF SPECIMENS.
Fig. 7

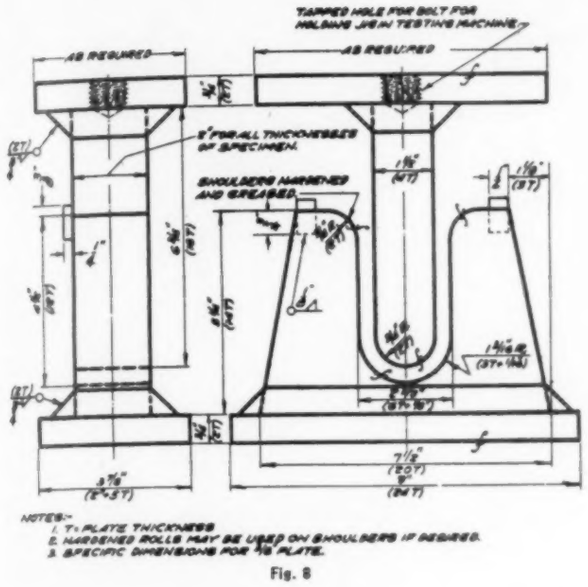

TAPPED HOLE FOR BOLT FOR HOLDING JIG IN TESTING MACHINE
AS REQUIRED
AS REQUIRED
SHOULDERS HARDENED AND GREASED
NOTES:-
1. T = PLATE THICKNESS
2. HARDENED ROLLS MAY BE USED ON SHOULDERS IF DESIRED.
3. SPECIFIC DIMENSIONS FOR 3/8" PLATE.

Fig. 8

15. Specimens shall be bent to the full capacity of jig. Any specimen in which a crack or opening exists before the bending, or results from the bending, exceeding $^1/_8$ inch (unless otherwise specified) measured in any direction, shall be rejected. No elongation data are required.

For the Good of the Service

By G. L. WILEY†

WE HAVE technology and technologies to throw away, technicians to burn, but still we have a shortage of skilled welders.

Welding is here to stay, its growth the past few years has been phenomenal. The few "bugs" that are still left in it are now the problem of the supervising welders. Let them ask themselves these questions—(1) "What strides or effort have I made to make available to my welders the improvements in welding technique, equipment, filler rods, procedures and latest results in research findings to help them combat the problems they are wrestling with? (2) How many of my welders could I completely entrust with a highly important welding job, refrain from giving any instructions as to procedure, fabrication, safety, allowance for distortion or stresses, and go home and sleep well that night?"

The supervisor who knows the part that the proper filler rod, procedure, allowances and technique play in the welding of today's all-welded structures, high-temperature and high-pressure alloy piping, realizes that there is still a shortage of trained welders.

The sooner this is realized and a new educational program on welding and qualifying is instituted along lines and specifications suggested by the AMERICAN WELDING SOCIETY the tail of this giant industry will at least begin to wag.

Equipment, filler metal, machine cutting, both flame hardening and softening, research developments of design and procedures are far ahead today of the human element that enters into the weld; hence, the paramount necessity of passing these new developments and achievements on to the "man behind the mask."

What we need now is a taste of "the good old days" when every worker took pride in his work.

We are getting the cart before the horse, but to make it worse we do not even have the harness (various codes) buckled on. We must tighten up on the belly-band and clean out some of our stables (institute educational courses of instruction in all phases of welding) before the insurance companies' inspectors do it for us.

In a majority of the smaller fabricating shops and plants the welders are capable of producing sound welds, providing they are instructed before hand in a carefully outlined process or fixed procedure. Sound welds cannot even then be made if obsolete or wornout equipment or poor materials are used. Most failures in welding today can be charged to poor designing, bad fit-ups and the demand for speed.

The welder is called upon now to have some conception of blue-prints, metallurgy, design, heat treatment of metals, procedures, various techniques and contraction and expansion. Today's welders should develop the habit of scientific thinking of each welding problem they encounter, secure the facts, analyze and classify them, draw conclusions, do the job, and finally check the results of the finished product. Following a definite procedure instead of the old "hit or miss," "cut and fit" method, will in time become a habit developed where it really functions in the individual "human element" of welding.

In our plant, daily meetings are held by the welders and the latest developments discussed with the aid of blackboard chalk talks. You would be surprised to see how eager the entire personnel of welders are for the opportunity to improve their ability. Other shops and plants would receive a surprise if they would give their welders a qualifying test in accordance with the A.S.M.E. Code for class U-68 Unfired Pressure Vessels. When the welders realize the significance of qualifying for these tests (for it will be only a short time before it will universally be mandatory) you will have a full attendance at all meetings. Topics discussed and explained at our chalk talks include the following: Stress relieving and heat treating, stresses and strains in welding, design of connections, proper bevel for various thicknesses of plate and pipe, peening and cleaning of welds, manipulation of rod in vertical and overhead welding, use of bevel and circle cutting machine, importance of initial bead at root, blue print reading, safety and cooperation with other departments.

You will have no dull moments if you will give each welder, as we have done, a questionnaire of 30 questions pertaining to welding problems of today that every well versed operator should know. But does he? From the return of these questionnaires you will have a yardstick to guide you in what is lacking in your welding set up. These questions can then be discussed and cleared up. Give your welders half a chance and they will enthusiastically take hold of the opportunity to qualify and improve their knowledge of today's welding requirements. Our welders to a man, who have not been trained in blue-print reading in laying out work, are taking kindred subjects at night school. In addition the company conducts a blue-print reading school for all employees who desire to attend. We also keep in close touch with all welding operations here and elsewhere. There is gold in your own back yard in plants in your own vicinity if you will only visit them and discuss your various welding problems.

† Welding Consultant, Mid-Continent Petroleum Corp., Tulsa, Okla.

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WELDING SOCIETY ACTIVITIES
AND RELATED EVENTS

Pittsburgh Section Plans Tri-State Regional Conference

The Executive Committee of the Pittsburgh Section has completed plans for a Tri-State Regional Welding Conference to be held in the William Penn Hotel on the afternoon and evening of Friday, April 29th. The conference will be conducted as a joint meeting of the AMERICAN WELDING SOCIETY, Pittsburgh Section and the Engineers Society of Western Pennsylvania. Invitations have been extended to plant executives and others interested in welding in Western Pennsylvania, Eastern Ohio and West Virginia.

Mr. K. F. Treschow, Secretary of the Engineering Society of Western Pennsylvania has cooperated splendidly with the Executive Committee in its plans for the conference. The Arrangements Committee consists of Messrs. K. F. Treschow and J. F. Minotte, Secretary of the Pittsburgh Section. L. C. Bibber, Chairman of the Pittsburgh Section, has been making arrangements with speakers and offers the following attractive program:

Afternoon Speakers:

Mr. R. E. Kinkead, Consulting Engineer, "Welding in the Production of Steel."

Mr. A. S. Low, V.P. and Chief Engr., Austin Company, Cleveland, Ohio, "Welded Construction in Some Recent Industrial Buildings," illustrated by motion pictures.

Motion pictures on the flash welding of rails and on welding arcs by the General Electric Company.

Evening Speakers:

Mr. P. J. Lang, Chief Engineer, Baltimore & Ohio Railroad and President of the AMERICAN WELDING SOCIETY.

Mr. A. E. Gibson, President, Wellman Engineering Co. and Past-President of the AMERICAN WELDING SOCIETY.

Mr. H. C. Hettelsater, Executive Engineer, The Harnischfeger Corporation, "Welding in the Construction of Cranes and Power Excavators."

Arrangements have been made with the William Penn Hotel to serve a dinner between meetings to those who desire it, offering an opportunity for out-of-town guests to become better acquainted with the members of the Pittsburgh Section and other visitors.

Welded Caissons

As the new Bronx-Whitestone Bridge, spanning the East River in New York City, takes shape, the engineering importance of the early foundation work becomes even more apparent.

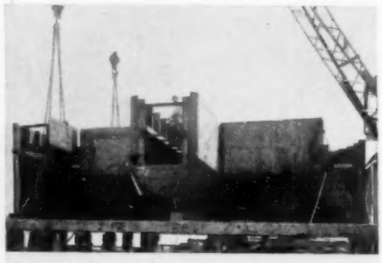
Of special interest are the two all-welded steel caissons which were sunk on the Bronx side, and which now support the twin concrete piers on that side. When delivered, these caissons were 38 feet square and 21 feet high, and had been towed by Moran Towing Company tugs from Wilmington, Del., to the site. The caissons had been assembled and launched by the Dravo Corporation at their Wilmington yards from sections fabricated in Pittsburgh, Pa. When launched the caissons had a draft of seven feet.

At the caissons were sunk, by jetting through eight-inch pipes, additional lift sections each 10 feet 6 inches high were added, bringing the total structure to 110 feet 3 inches. At the 89-foot stage, concrete was poured into the caissons, forming a sturdy concrete and steel foundation for the concrete piers. Each steel lift ring was fabricated in eight sections in Pittsburgh, and shipped directly to the site for addition to the caissons.

Besides the caissons, Dravo Corporation provided Frederick Snare Corporation, the general contractors, with two all-welded cutting edges measuring 100 feet by 33 feet, two square cutting edges 38 feet by 38 feet, and two circular cutting edges 24 feet in diameter. These cutting edges were 4 feet high and were used in construction of the reinforced concrete foundation piers on the Queens side.

Prompt delivery of the floating caissons was important since construction had to conform strictly to schedule. As a result, the first cutting edge was delivered 30 days after receipt of the order, and the first floating caisson was delivered in eight weeks.

Arranging Sections of Steel Cutting Edges Prior to Welding



Method of Assembly of Floating Caisson Is Shown. Note Size of Sections

Floating Caisson Nearing Completion, Final Left Sections Being Welded

Launching of Floating Steel Caisson in Christiana River, Dravo Yards, Wilmington, Del.

WELDING HANDBOOK

The Editorial Committee is proceeding diligently in completing the Handbook and is now in a position to submit a list of the probable chapters of the Handbook. This list is reproduced below. Although no definite date can be given at which time the Handbook will be available for distribution, present indications are that the book will be available to members about June 1st.

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Fourth Annual Welding Conference School of Engineering and Architecture

University of Kansas, Lawrence March 31st and April 1st, 1938

The Fourth annual Welding Conference at the University of Kansas furnished an opportunity to hear discussions of welding by those who are actively engaged in all phases of its utilization.

The University gratefully acknowledges the assistance of the New York Office and of the Kansas City Section of the AMERICAN WELDING SOCIETY in the preparation of this program.

Thursday Morning, March 31st

Auditorium, Marvin Hall

8:30 Registration

9:30 Chairman, Professor F. A. Russell Professor Civil Engineering, University of Kansas.
Maintenance and Repair of Heavy Construction Equipment: T. B. Jefferson, Assistant Plant Engineer, U. S. Engineer Dept., Fort Peck, Mont.

10:30 Engineering Convocation.
Welcome: Dr. E. H. Lindley, Chancellor, University of Kansas.
Address: Welding at the A. O. Smith Corporation, Wm. E. Crawford, Chief Engineer, A. O. Smith Corporation, Milwaukee, Wis.
Metal Inspection and Magnaflux Methods: J. W. Vale, Educational Director, T. W. A., Kansas City, Mo.

Afternoon

Chairman, La Motte Grover, Dept. of Applied Mechanics, Kansas State College, Manhattan, Kansas.

1:30 Code Procedure under Section U-69, A. S. M. E. Unfired Pressure Vessels: Ed. H. Gill, Chief Engineer, Columbia Steel Tank Co., Kansas City, Mo.
Developments in Welding: G. F. Dickens, Manager, Air Reduction Sales Co., Kansas City, Mo.
Hard Surfacing: W. S. Tromley, District Sales Manager, Haynes Stellite Co., Tulsa, Oklahoma.
Metal Spraying: Hugh Libby, Libby Radiator Works, Kansas City, Missouri.
Fowler Shops—Demonstration of Metal Spraying, Preparation, Application and Finishing. Hugh Libby.

Evening, Fowler Shops

Demonstration: W. R. Clark, Jr., Manager, Kansas City Branch, Linde Air Products Co. Metal Cutting, Metal Coating, Flame Hardening and Lindwelding.

Friday Morning, April 1st

Marvin Hall

Chairman, R. W. Warner, Professor and Head of the Department of Electrical Engineering, University of Kansas.

9:00 Training Welders for the Oil Field Industry: L. T. Detlor, Carter Oil Company, Seminole, Oklahoma.
Arc Welding Electrode Coatings: F. Emery Garriott, Metallurgical Engineer, J. D. Adams Company, Indianapolis, Indiana.
Flame Hardening: F. C. Hutchinson, Chief Developing Engineer, Kansas City District, Linde Air Products Company.
Boiler Manufacture and Repairs: D. J. Cody, Cody Boiler Works, Kansas City, Missouri.

Afternoon

Chairman, C. A. Woodman, Purchasing Agent, Kansas City Bridge Co., Kansas City, Mo. Chairman, Kansas City Section, A. W. S.

1:30 Pipe Line Welding by the Electric Welding Method: Harold C. Price, Manager, H. C. Price Co., Bartlesville, Oklahoma.
Welding in the Petroleum Industry: W. M. B. Brady, Welding Specialist, General Electric Co., Chicago, Ill.
Address: P. G. Lang, Jr., Chief Bridge Engineer, B. & O. Railroad Co., President, AMERICAN WELDING SOCIETY.

Evening

Annual Meeting, Kansas City Section, AMERICAN WELDING SOCIETY, Hotel Kansas Citian, Kansas City, Mo.

Power Exposition

Announcement has just been made that the Thirteenth National Exposition of Power and Mechanical Engineering will be held this year at Grand Central Palace, New York City, during the week of December 5th to 10th. Since its inception in 1922, the Power Show has become the traditional means by which the industry's manufacturers and engineers convene to take inventory of power equipment advances. Manufacturers in the power and allied fields will display their latest products; and professional engineers, public utility executives, dealers and technical operatives will be on hand to inspect the latest machine and material developments, and to weigh comparative values.

Award of Medals

I. Regulations Governing the Board of Awards

1. *Membership.*—The Board of Awards shall consist of three members of the AMERICAN WELDING SOCIETY. One member shall retire each year. The President of the Society shall appoint a member each year to serve from the first day of the month next following the first session of the annual meeting of the Society for a term of three years. The senior member of the Board shall be chairman of the Board of Awards.

2. *Duties.*—The Board of Awards each year shall select the persons to receive the awards made by the Society.

II. Regulations Governing the Award of the Samuel Wylie Miller Memorial Medal

1. *Donor.*—The AMERICAN WELDING SOCIETY.

2. *Purpose.*—To commemorate the many unique contributions of Samuel Wylie Miller to the science and art of welding, his unselfish encouragement of others, his achievements and effective work in convincing engineers and the public that welding should take its rightful place as a recognized method of fabricating metals, and especially his important contributions to the formation and early success of the AMERICAN WELDING SOCIETY.

3. *Award.*—The medal shall be awarded each year to the person who in the judgment of the Board of Awards is most deserving for conspicuous contributions to the advancement of the welding or cutting of metals.

4. *Eligibles.*—Any person shall be eligible for this award whether or not a member of the AMERICAN WELDING SOCIETY.

5. *Presentation.*—The medal for each year together with a suitable certificate shall be presented at a session of the Annual Meeting of the AMERICAN WELDING SOCIETY next following the year for which the award is made. The presentation shall be made by the chairman of the Board of Awards or by a member of the Society designated by the chairman.

III. Regulations Governing the Award of the Lincoln Gold Medal

Regulations governing the award of this Medal are given elsewhere in this issue.

IV. Regulations Governing the Award of the Industrial Prizes

1. *Donor.*—The Industrial Publishing Company.

2. *Purpose.*—To stimulate interest in the profession of welding engineering in the Land Grant Colleges including the study of the different welding processes and the art of designing structures for fabrication by welding.

3. *Awards*

(*a*) *The Industrial Arc-Welding Prize.*—The Industrial Arc-Welding Prize of $250 shall be awarded each year for the thesis written by a senior student or students either on the use of arc welding or on the design of structures of any kind for fabrication by arc welding which in the judgment of the Board of Awards is the most deserving of this prize.

(*b*) *The Industrial Gas Welding and Cutting Prize.*—The Industrial Gas Welding and Cutting Prize of $250 shall be awarded each year for the thesis written by a senior student or students on the welding of metals by the gas process, the gas cutting of metals or on any application of gas to the fabrication or to cause a change in any of the properties of metals which in the judgment of the Board of Awards is most deserving of this prize.

4. *Eligibles*

(*a*) For the author or authors to be eligible for either of these prizes they shall be senior students in a Land Grant College. The thesis shall have been approved by the head of the department in which the author or authors were enrolled.

(*b*) Three copies of the thesis and the written approval shall have been received by the Board of Awards not less than thirty days previous to the first session of the Annual Meeting of the Society in the year for which the prizes are awarded.

(*c*) A thesis considered for either of these prizes shall contain no statement which might be considered as advertising or sales promotion.

(*d*) A thesis having more than three authors shall not be considered for either of these prizes.

5. *Presentation.*—The prizes together with suitable certificates shall be presented at a session of the Annual Meeting of the AMERICAN WELDING SOCIETY during the calendar year for which the awards are made by the chairman of the Board of Awards or by a member of the Society designated by the chairman. Each author of the thesis for which the prize was awarded shall receive $250 and a certificate and the certificates shall be duplicates.

Board of Awards to Select 1938 Winner of Lincoln Gold Medal

A board of awards, composed of H. L. Whittemore, chairman, and Messrs. G. T. Horton and A. G. Oehler, was appointed in January by the executive committee of the AMERICAN WELDING SOCIETY, to have charge of selecting the recipient of the Lincoln Gold Medal for 1938. Following appointment, the board drafted regulations governing award of the medal which has been accepted by the Society for annual award. The regulations follow:

Regulations Governing the Award of the Lincoln Gold Medal

"1. *Donor.*—Mr. J. F. Lincoln, President, Lincoln Electric Company.

2. *Purpose.*—To encourage the presentation before the AMERICAN WELDING SOCIETY of papers which are effective in promoting the use of welding.

The Lincoln Gold Medal Which Is to Be Awarded Annually by the American Welding Society. Illustration at Bottom Shows How Recipient's Name Is Lettered in Relief on Reverse Side

3. *Award.*—The medal shall be awarded each year to the author or authors of the paper which in the judgment of the Board of Awards is the greatest original contribution to the advancement and use of welding.

4. *Eligibles*

a. For the author or authors to be eligible for the award, the paper shall describe clearly original work done by them or under their immediate supervision on welding in any of its aspects and by any method or process.

b. For the author or authors to be eligible for this award the paper shall have been published in the AMERICAN WELDING SOCIETY JOURNAL for the period beginning with the issue next following the Annual Meeting issue for the year next preceding the year for which the award is made and ending with the Annual Meeting issue for the year for which the award is made, and also, the paper shall have been presented or scheduled for presentation either at any meeting of the AMERICAN WELDING SOCIETY or a meeting of any section of the Society.

c. A paper considered for this award shall contain no statement which might be considered as advertising or sales promotion.

d. The paper shall be a full disclosure of the subject.

e. Papers having more than three authors shall not be considered for this award.

f. Any one may be an author of a paper considered for this award whether or not a member of the AMERICAN WELDING SOCIETY.

5. *Presentation.*—The medal, bearing on the reverse side the name of each author of the paper, together with a suitable certificate, shall be presented at a session of the Annual Meeting of the AMERICAN WELDING SOCIETY during the year for which the award is made by the chairman of the Board of Awards or by a member of the Society designated by the chairman. Each author of the paper for which the award was made shall receive a medal and a certificate and the medals and certificates shall be duplicates."

The medal is inscribed as shown in the accompanying illustration. One side bears the wording "Lincoln Gold Medal Award —AMERICAN WELDING SOCIETY," encircling a central figure which is symbolic of electric welding. The reverse side will be lettered in relief with the name of the winner and date of presentation as indicated by the lower figure of the illustration which shows the inscription of the 1937 award made to T. M. Jackson for his paper entitled "Welding in Tanker Construction."

A Unique Application

Through the courtesy of Mr. W. Gerritsen, representing the firm of Willem Smith & Company, Nijmegen, Holland, and Mr. F. T. Llewellyn of the United States Steel Corporation, we reproduce the photograph below.

It depicts a wind mill in regular operation in the country of Holland. The photograph was taken at a time when the wings to the upper right and the lower left were made of steel fabricated by means of welding, while the two other wings show the conventional wood frame construction which, when in use, is covered by some kind of textile fabric.

N. E. M. A. Standards for Welding Electrodes are Circulated

Standards for Welding Electrodes have recently been adopted by the Electric Welding Section of National Electrical Manufacturers' Association and arrangements have been made to distribute them through member companies and from

N. E. M. A. headquarters at 155 E. 44th Street, New York City. The principal functions of these standards are: (1) to define the various classes of metallic electrodes used in arc welding; (2) to standardize the packaging, diameters and lengths of the various types of electrodes.

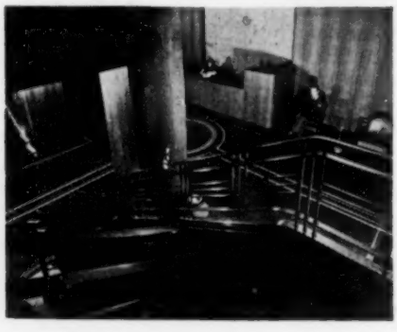
For the purposes of standardization electrodes are divided among the following nine classes: bare, thinly coated, heavily coated, high tensile, hard surfacing, ferrous for cast iron, corrosion and scale resisting alloy, non-ferrous and miscellaneous. This portion of the standards alone is thought capable of eliminating a large amount of confusion and misunderstanding in the trade if widely adopted. It is also helpful to have a general understanding as to how electrodes should regularly be packaged, and in what range of diameters and lengths for the various classes, other packaging and dimensions to be considered special.

Broadcast Studio

Clevelanders by the thousand poured into the most modern broadcasting studios between New York and Hollywood recently, as NBC opened what are believed to be the first complete skyscraper street level studios built by the radio industry.

Occupying the first four floors of a 20-story office building within two blocks of Cleveland's civic, financial and shopping centers, WTAM, a 50,000 watt key station of the NBC network, has come down where the whole town can see it. A total of $300,000 was expended in rebuilding and equipping the station's quarters, formerly occupied by bank vaults and a lofty banking lobby which the building owners long despaired of renting.

Thanks to the application of structural welding, two floors now fill the space formerly occupied by the towering colonnaded lobby. Entering directly from the street, station visitors find a broad comfortable reception lobby with flooring of colorful inlaid linoleum and walls completely surfaced by a rich lacewood veneer. Angles are almost completely missing in this room where modern furniture and lighting, together with a streamlined telephone and reception desk, complete the picture. A lounge, equally striking in furnishings and decoration, adjoins the lobby, and three smaller studios beyond it are reached through a richly carpeted guest corridor.



A Lofty, Ornate, and Unrentable Banking Lobby Has Been Converted by Modern Materials and New Structural Techniques Into Five Acoustically-Perfect, Sound-Proof Broadcasting Studios, Reached from This Entrance Lobby. Built by The Austin Company, Engineers and Builders. These Studios Represent the Industry's First Street Level Skyscraper Broadcasting Station

All traces of the building's gilded columns have disappeared behind this rich lacewood veneer and other special materials used to produce ideal broadcasting conditions in the studios, each of which has its own individual control and observation rooms

Interests of Members of American Welding Society

In order to ascertain the interests of members of the AMERICAN WELDING SOCIETY in various types of papers, the Meetings and Papers Committee sent out a questionnaire to all members of the Society. Each member was asked to place two checks to indicate major preference and one check to indicate general interest in a specific subject. In counting the votes, major interest has been arbitrarily given two votes and minor interest one vote. The results of the questionnaire are reproduced below.

RESULTS OF QUESTIONNAIRE AMERICAN WELDING SOCIETY

FIELDS OF INTEREST

No. of votes	
476	Maintenance and Repair
508	Construction
504	Production and Manufacture
355	Research, Fundamental
417	Research, Industrial
472	Design Methods and Data
218	Economics
500	Metallurgy
295	Development Work
254	Educational
250	Operation

TYPE OF PAPERS

374	Apparatus and Equipment
654	Techniques, Procedures
445	Test Results
323	Filler Metal
369	Theory
487	Specification and Codes
405	Inspection, Training
217	Acceptance Requirements
263	Safety
198	News
186	Pictorial Reviews
373	Jigs and Fixtures

METALS

684	Low-Carbon Steel
725	Alloy Steel
446	High-Carbon Steel
321	Cast Iron
335	Cast Steel
341	Copper, Brasses and Bronzes
336	Aluminum and its Alloys
294	Other Non-Ferrous Metals

WELDING PROCESSES

812	Arc, D. C.
635	Arc, A. C.
452	Gas
281	Resistance
122	Thermit
305	Cutting Hand
337	Cutting Machine
185	Atomic Hydrogen

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245	Aircraft and Automotive
306	Shipbuilding and Repair
258	Railroad and Railway, Shops
200	Railroad and Railway, M. of W.
491	Pipe Lines and Piping
572	Pressure Vessels
507	Welding Shop and Maintenance Problems
448	Tanks
521	Structural Steel and Bridges
329	Light Gauge Production Work
344	Machinery
439	Hard-Facing and Surfacing
180	Steel Mills
259	Metal Spraying
222	Low-Temperature Brazing
270	Bronze Welding
310	Flame Hardening and Softening
272	Oil Industry

Safety Goggles

A chart which specifies types of safety goggles to wear for protection against eye hazards in all principal industries has just been completed by the Safety Engineering division of American Optical Company, Southbridge, Mass. Upon request, it will be sent to any industrial concern without cost.

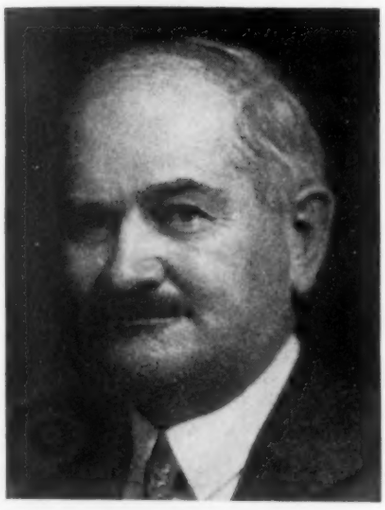
Probably the most concise and complete chart of its kind, it classifies eye hazardous operations by industries and recommends specific types of eye protection equipment which have been developed for each hazard.

The chart was designed to aid industry select the proper safety equipment needed in the fight to reduce the annual 200,000 industrial eye injuries.

Golden Anniversary

We are happy to announce that Mr. and Mrs. Fred E. Rogers of 6 Garfield Place, East Orange, N. J., celebrated their 50th wedding Anniversary at their home on Washington's Birthday, February 22, 1938. Mrs. Beatrice Daniel, a daughter, came East from San Francisco for the celebration. The others giving the party were a son and daughter-in-law, Mr. and Mrs. Gilbert Earl Rogers of Dover, and a son-in-law and daughter, Mr. and Mrs. John L. Mahoney of Upper Montclair.

Mr. and Mrs. Rogers moved to East Orange forty years ago when Mr. Rogers became Associate Editor of *Machinery*, a trade journal. For the past sixteen years Mr. Rogers has been employed by the Air Reduction Sales Company, editing an inter-office publication and acting as technical advisor. Mr. Rogers is 71 and Mrs. Rogers 68.



Fred E. Rogers

Mr. Rogers has been active in the work of the AMERICAN WELDING SOCIETY since its inception. At one time he was President of the Service Engineering Company, New York, and joined the Davis-Bournonville Co., Jersey City in September 1918. He is a charter member of the AMERICAN WELDING SOCIETY and was a member of the Advisory Committee of the Emergency Fleet Corporation.

Mr. Rogers has been active in committee work and particularly those committees relating to technical program and publications of the Society. He has also served on the Committee for the first award of the Lincoln Gold Medal.

Mr. Rogers is widely known as an author in the welding field. He has written many articles for the leading trade journals, handbooks, bulletins, pamphlets, particularly relating to welding and cutting. He is inventor of the Rogers Variable Speed Transmission for Motor cars and trucks. He is a Past-Chairman of the New York Section.

Industrial Research Laboratories

Revision of Bulletin 91, National Research Council

The increase in the number of research laboratories maintained by industrial concerns in the United States during the last few years has made it seem desirable to issue a new edition of the National Research Council's Bulletin, "Industrial Research Laboratories of the United States," fifth edition.

On March 25th questionnaires were mailed to the 1562 concerns which were included in the last edition of 1933, and to a large number of new concerns which are thought to maintain laboratories.

If the reader of this note is a member of a firm which maintains a laboratory where research looking toward the development and improvement of products is carried on, it is hoped that he will ascertain whether a questionnaire has been received by his company, and if not that he will request one from the Library, National Research Council, 2101 Constitution Avenue, Washington, D. C.

There is no charge for the entry in the bulletin, the only requirement being that the laboratory is undertaking research.

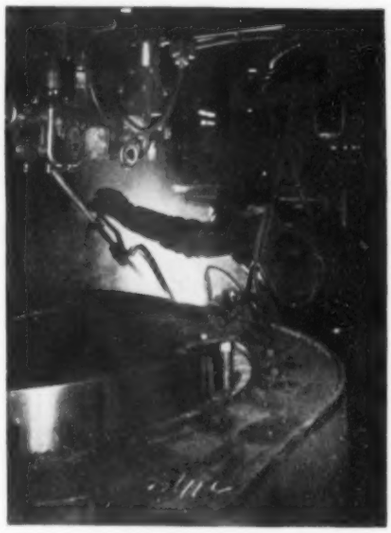
It is desirable to have the information for the bulletin in hand as soon as possible so that the publication may appear within the current year.

Aluminum Fluxes

The Wooldridge Aluminum Welding Products of Glastonbury, Conn., has issued an attractive instruction manual for the use of their fluxes for the welding of aluminum by the torch and arc. Copies may be obtained upon request.

Manufacturing Motors

Stitching Steel. Operators Welding Magnet Frames for Direct Current Motors and Generators



Automatic Sewing Machine. A Large Automatic Welding Machine "Stitching" the Wrapper Plate to the Rest of the Stator Frame of a Big Synchronous Motor in General Electric's Schenectady Plant

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SECTION ACTIVITIES

BIRMINGHAM

On Monday, February 28th, the Birmingham Section held an open discussion meeting. Many interesting questions and answers were brought to light. Sixty attended with every one well pleased with the results.

BOSTON

Two interesting papers were presented at the February 25th meeting of this Section, which was held at the Massachusetts Institute of Technology. Milton Male, Research Engineer of the U. S. Steel Corporation, spoke on the subject of "Low Alloy Steels and Their Welding." W. L. Warner of the Watertown Arsenal discussed "Zones Adjacent to Welding." Both papers were illustrated with lantern slides. At the conclusion of presentation of papers, Chairman Horgan invited Dr. W. Gordon Theisinger, Welding and Metallurgical Engineer of the Lukens Steel Company, to open the discussion period.

Prior to the presentation of papers, a fifteen-minute sound film was shown in the interest of the Greater Boston Community Fund.

The following Safety Program was scheduled for the March 25th meeting of the Section, which was held in Room 1-390 at the Massachusetts Institute of Technology.

Speaker: H. A. Sweet, Engineer, Assoc. Factory Mutual Fire Insurance Company.

Subject: "Preventing Cutting and Welding Fires."

Speaker: W. M. Pierce, Chemical Engineer, Employers Liability Assurance Corporation.

Subject: "Safety Hazards of Welding from the Standpoint of Health and Personal Accident."

Speaker: Roger Clark, Engineer, General Electric Company.

Subject: "Inspection of Welding."

CHICAGO

The Chicago Section met on the night of the 18th for its February meeting at which Charles H. Jennings, research engineer, Westinghouse Electric & Mfg. Co., presented a talk on "European Welding Practice." His talk covered the observations made in a four months trip through European countries from which he has recently returned. The exceptionally large turn-out found much of interest in Mr. Jennings' observations.

The March meeting was held on the 18th in the Skytop Room. Dr. W. G. Theisinger, Welding and Metallurgical Engineer of the Lukens Steel Company, addressed the meeting on "Heat Effect in Welding." Dr. Theisinger answered many questions on the findings of an extensive research program into hardness areas adjacent to the weld.

CINCINNATI

Meeting of the Cincinnati Section was held in the Auditorium of the Ohio Mechanics Institute, on Thursday, March 17th at 8 P.M. This was a joint meeting with the Engineers' Club of Cincinnati. The speaker of the evening was Dr. J. C. Hodge, Chief Metallurgist of the Babcock and Wilcox Company, whose subject was "Modern Welding Methods." Some interesting data and facts about high pressure boiler welding were given.

CLEVELAND

The fifth meeting of the season of the Cleveland Section was held on March 9th in the Bingham Building, Case School of Applied Science. Mr. Harvey Bass, N.Y.C.R.R., Collinwood Shops, presented an address on "Machine Gas Cutting of Locomotive Parts." The paper was illustrated with slides and was enjoyed by all those present.

CONNECTICUT

An enlightening discussion of the various types of welding arcs, including suggested comparisons, was made before the February meeting of the Connecticut Section by Mr. E. Vom Steeg of the General Electric Co Mr. Vom Steeg with a background of twenty years in the welding business had a number of finger-tip answers to problems which proved to be of intense interest to both operators and engineers.

DETROIT

The regular monthly meeting of the Detroit Section was held on March 17th in the Detroit Leland Hotel. Mr. R. W. Brendle, of the Great Lakes Engineering Works, was the speaker of the evening. His subject was on the All-Welded Freighters: "Green Island" and "Norfolk." Mr. Brendle's talk was descriptive of outstanding examples of welded construction in shipbuilding and was illustrated with slides.

HAWAII

A very interesting program was given at the January 27th meeting of the Hawaii Section. Mr. Colburt, of the Honolulu Technical School, explained some of the aims of the school and followed with a talk on the Metropolitan Water District Pipe Line of California on which project he had worked for some time. Other talks were given that proved very interesting. Mr. H. E. York brought out some points of welding in connection with insurance work. Mr. McCleery, of Ewa Plantation, gave some interesting side lights on pipe line fabrication and welding.

INDIANAPOLIS

The Indianapolis Section was invited to participate in the 58th Annual All Engineers' Meeting under the auspices of the Indiana Engineering Council, which was held all day Friday, February 25th at the Hotel Lincoln. An All Engineers' Dinner was held at 6:30 P.M. Following the dinner there was an address by Mr. L. W. Wallace, Director of Research and Development for Crane Company, on "The Engineer and Civilization." The Secretary of the Indianapolis Section advises that plans are well under way for the establishment of an Engineering Club Room.

MARYLAND

The Maryland Section held their regular monthly meeting on February 18th at the Engineers' Club in Baltimore, Mr. T. W. Greene of The Linde Air Products Company spoke on "Testing of Welds." A lively discussion followed this interesting talk.

MILWAUKEE

The Milwaukee Section held a Technical Meeting on Thursday, March 10th at the City Club of Milwaukee. Dinner preceded the meeting. An illustrated talk by Dr. S. L. Hoyt, Director of Metallurgy, A. O. Smith Corp., on "Metallurgical Studies of Arc Welds," dealt with the fundamental reason for the recent wide spread use of metallic arc welding—weld metal quality. This was shown by results of studies of microstructure, gas content and metallurgical characteristics of both the old and the modern type of weld metal.

NORTHWEST

E. R. Seabloom, Research Welding Engineer, Research Testing Laboratories, Crane Company, Chicago, gave a most interesting lecture Thursday, March 17th, at the Minnesota Union, University of Minnesota, before a large audience composed of members and friends of the Northwest Section upon "Pipe Welding," which was illustrated by lantern slides.

A motion picture was also shown entitled "Arc Welding, the World's Largest Atom Smasher" produced for the Westinghouse Electric & Mfg. Co., Pittsburgh, Pa., and obtained for the occasion by N. N. Canfield of the Commercial Gas Company, Minneapolis. It aroused a great deal of interest.

The meeting was preceded by a dinner at which was discussed the proposed amendments to the by-laws of the national Society.

The Northwest Section is consistently increasing its membership by filling a long felt need among the metal industries of

the northwest. At many of the meetings members and guests frequently come 125 miles from cities and towns in this district merely for the benefit they derive from hearing the discussion of subjects of immediate importance to all who are engaged in the art and science of welding.

The Linde Air Products Company and the Minneapolis Iron Store Company conducted a joint welding, painting and equipment conference at the Minneapolis Iron Store on March 16th and 17th, which was largely attended.

OKLAHOMA CITY

What proved to be the largest meeting held to date by the Oklahoma City Section was a special meeting held on February 25th at which time Mr. E. W. P. Smith, Consulting Engineer for The Lincoln Electric Company, was the speaker. Mr. Smith chose as his subject the "Study of Stress Distribution by Means of Polarized Light." The early portion of the talk was accompanied by slides illustrating the various points discussed, but the feature of his talk was the demonstration of stress distribution by means of celluloid models subjected to stresses and a study of these stresses as made possible by projecting the image on a screen by means of a polariscope.

A lecture course consisting of five lectures is being started March 10th continuing through until April 21st. This course will consist of lectures and demonstrations on such subjects as: "Arc Welding," "Gas Welding," "Structural Welding," "Inspection of Welds" and "Effects of Welding on Materials."

In view of the special meeting held February 25th and the lecture course starting March 10th, the regular monthly meeting for March was cancelled.

The memberships of the Oklahoma City Section continue to increase and with the announcement of the lecture course many new members have come in.

Further information on the lecture course is given below:

LECTURE COURSE

MARCH 10th—7:30 P.M.

Subject: "Arc Welding," by J. Le Treyte Lang, Marquette Mfg. Co., Okla. Natural Gas Co. Bungalow, 1st Floor Key Bldg., N. W. Cor., 3rd and Harvey. OPEN TO MEMBERS AND FRIENDS.

MARCH 17th—7:30 P.M.

Subject: "Gas Welding," by M. F. (Pete) Dunne, Air Reduction Sales Company, Air Reduction Sales Co. Plant, 1521 Agnew. OPEN TO MEMBERS ONLY.

MARCH 23rd—8:00 P.M.

Subject: "Effect of Welding on Base Metals," by W. G. Theisinger, Welding & Metallurgical Engineer, Lukens Steel Company, Biltmore Hotel—Parlor A. OPEN TO MEMBERS AND FRIENDS.

APRIL 14th—7:30 P.M.

Subject: "Inspection of Welds and Method of Testing," by J. L. Owen, Inspector, Hartford Steam Boiler Insp. & Ins. Co., Okla. Gas & Elec. Co. Bungalow, Basement Okla. Gas & Elec. Bldg., S. W. Cor. 3rd & Harvey. OPEN TO MEMBERS ONLY.

APRIL 21st—7:30 P.M.

Subject: "Structural Welding," by L. E. Acker, Engineer, J. B. Klein Iron & Fdry. Co., Okla. Gas & Elect. Bungalow. OPEN TO MEMBERS ONLY.

Admittance to meetings listed "For Members Only" will be upon presentation of membership card.

PHILADELPHIA

There was a very good turnout to hear Mr. W. E. Hollingshead, of the Engineering Department, S. Morgan Smith Company, present a paper entitled "The Uses of Castings on Heavy Welding Assemblies," at the February meeting held on the 21st. This same paper was presented at a joint meeting with the Bethlehem Department of the A. S. M. E. held on March 7th at Lehigh University.

A representative of the U. S. Steel Corporation spoke on the popular subject "Fabrication and Uses of High Yield Strength Alloys" at the March 21st meeting.

On April 18th at the Engineers' Club Mr. Lawson of Bethlehem Steel Company will speak on "Welding in Modern Building Construction."

There will be an inspection trip in the Philadelphia area in May.

The Philadelphia Section's Executive Committee have been planning for some time a sub Philadelphia Section Meeting in the Lehigh Valley. The first meeting was held in March.

PITTSBURGH

The largest number (over 350) yet to attend a meeting this season turned out to hear Mr. Everett Chapman, President of Lukenweld, Inc., present his talk on "Welded Steel Construction with Special Reference to Stresses, Design, Metallurgy and Heat Treatment," in the Blue Room of the Roosevelt Hotel, Wednesday night, March 16th. With the use of a blackboard, slides and a 1200-foot reel of films, Mr. Chapman gave one of the most interesting talks on stresses and heat treatment ever presented before the Pittsburgh Section. Following his presentation he was kept busy answering questions for about an hour.

Mr. H. S. Card, in charge of publicity for the "Tri-State Regional Conference," which is to be held here April 29th, gave an interesting talk on the arrangements to date, with a description of the papers and speakers already selected.

Mr. A. E. Marble, Chairman of the Membership Committee made an eloquent appeal for new members and outlined in a brief manner the many advantages to be obtained through membership.

Mr. W. W. Reddie, Representative on the Board of Directors, gave a very interesting report on the activities of the Society.

Following adjournment of the meeting, refreshments were served.

ST. LOUIS

February 11th Dr. V. N. Krivobok, Allegheny Steel Corp., addressed the Section on the subject of Stainless Steel and Its Weldability. Dr. Krivobok's talk was most interesting and instructive. Two hundred and five members and guests attended the meeting.

The March 11th meeting was sponsored by The Linde Air Products Company. An interesting paper with movies and slides was presented on the subject of Recent Development in Cutting Practice by Mr. R. F. Flood of this Company.

SAN FRANCISCO

The March meeting of the San Francisco Section was held on the 18th. At that time there was a discussion and a moving picture on the subject of Flame Hardening. In addition, there was an extended discussion relative to future programs.

The April meeting will be held on the 15th and the Section has been fortunate in securing Mr. L. C. Bibber, Welding Engineer for the Carnegie Illinois Steel Company, who will speak on the subject, "Welded Joints—Which Ones to Use and When and Why."

SAN JOAQUIN VALLEY

A new Section known as the "San Joaquin Valley Section" was organized February 24, 1938, with the following Officers:

Chairman—B. Rintoul, Taft, c/o Western Water Co. (Res. 562 Office 281).

Vice-Chairman—J. W. Steen, Box 1121, Taft, Ph. 640-J.

Secretary—H. S. Nix, Box 1364, Taft, Ph. 295-W.

Treasurer—I. K. Vandam, 2730 Sunset Ave., Bakersfield, Ph. 2431-W.

Executive Committee:

E. R. Harrison, Chairman, 218 Olive Ave., Taft, G. P. Corp.

O. W. Eagar, 503 Taylor St., Taft, F. P. Corp.

C. L. Ogiline, Rt. 1, Box 109, Arvin, H. S. Jewett Shop.

E. P. Van Leuven, 2716 21st St., Bakersfield. Inst. K. C. UH. S.

Floyd Smith, 722 L. St., Bakersfield. Motor Center.

Representative on National Board of Directors—Harry R. Hammett, Mgr., San Joaquin Valley Branch, Western Pipe & Steel Co.

Mr. K. Van Ness King, Regional Vice-President, Pacific Coast, was the honor guest of the evening. Mr. King congratulated the Section upon its progress and extended the assistance and cooperation of his office and that of the San Francisco Section to Members of the San Joaquin Valley Section whenever needed in their Section activities. The members of the Los Angeles Section also extended a most friendly greeting and best wishes for continued success through their Chairman, Mr. P. D. McElfish, who presented the Charter members of the Section with pins of the Society as a further token of friendship from the Southern group.

The illustrated lecture presented by Mr. Carl A. Wallace, Chief of the Bureau of Identification of the Ventura County, Sheriff's Office, was most interesting and highly educational in content.

Mr. Roy B. Southworth's presentation of the sound film "The Building of the Bay Bridges" was well received by all

those present. One hundred and eight were present at the meeting, this number being the largest so far.

The following tentative program was outlined by the Section:

March 31st, Bakersfield

Motion Pictures on the Manufacture of Pipe and Tube Goods by National Tube Co. Visit through the Southern Pacific Railroad Shop.

April 21st, Taft

"Alloying Elements in Welding Rods," by T. R. Walther, The Linde Air Products Co.

Mr. Bickham of the Fairchilds Aerial Surveys Co., Motion Picture and Lecture.

May 19th, Bakersfield

Election of Officers. Pan-American Airway's Travel Picture of the Caribbean and South America.

TULSA

The first dinner meeting was held on Thursday, February 24th with a total of 46 for dinner and in addition to this number there were some 35 or 40 attending the lecture afterwards. Because of the very short notice of this meeting, the attendance was phenomenal. The Temporary Officers are T. M. Heggie, Acting Chairman; Jay P. Walker, Acting Treasurer; Richard Thompson, Acting Secretary.

An Organization Meeting was held on March 3rd at which a Temporary Executive Committee was appointed consisting of the following:

Richard Thompson, Chairman
Emil Henkefent
L. W. McKelvey
R. L. Looney
L. R. Hodell

PROPOSED SECTIONS

TOLEDO

The second meeting of this proposed Section was held at the University of Toledo on Friday, February 25th. Mr. Bill Allen, spoke in the absence of Mr. J. D. Gordon of The Taylor Winfield Corporation, on the subject "Welding in Industry Today." There was an attendance of 128.

TRI-CITY

A very successful meeting on Resistance Welding was held at Rock Island Arsenal Auditorium on February 28th. There were 75 at the dinner and 175 at the meeting. Mr. Weiger and Mr. Harris presented very interesting papers on "Resistance Welding Theory and Practice," the former covering theory and the latter practice. Mr. C. H. Burgston of the Deere & Company acted as Chairman of the meeting and kept the discussion interesting with a number of questions pertaining to the subject of the meeting.

WICHITA

Meeting held on February 23rd with an attendance of 104 was a decided success. The speaker of the evening was Mr. E. W. P. Smith, E.E., Consulting Engineer for The Lincoln Electric Company, whose subject was "Structural Steel Construction by Electric Arc." Mr. Smith's talk and pictures were very well received. An Executive Committee meeting was held on March 8th in the office of Mr. H. H. Minard, P.A., Coleman Lamp Co. Preparations were made for the next meeting which will be held on March 30th. Mr. Brady, of the General Electric Co., will speak on "Arc Welding in the Petroleum Industry."

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-257. Research Engineer desires position. Have had ten years' practical research experience involving investigations in Oxyacetylene, Arc and Resistance Welding. Have assisted in the development of Atomic Hydrogen process. Also work in copper brazing, use of fluxes, etc. Have experience in investigational work involving ferrous and non-ferrous metals, welding of unlike metals and the developing of electrodes. Have studied iron arc in air and shielded atmosphere.

A-258. First class welder desires position. 18 years' experience in Electric and Acetylene. Worked on the Boulder Dam, for the Babcock & Wilcox Company; 4 years on street cars and business; 4 years in railroad shops; 3 years construction. Also on the Akron Zeppelin; 2 years for the B. F. Goodrich Fire and Rubber Co. Has taken several tests and passed all. Can qualify for any job.

A-259. 100% Acetylene Welder on all metals. Learned tinsmith and welding at a very well known firm in Germany.

List of New Members

February 1 to February 28, 1938

BOSTON

Lee, Daniel A. (C), 496 Pleasant St., Malden, Mass.
Robbins, Alden (D), 342 Essex St., Whitman, Mass.

CANADA

McParlane, John (C), Hamilton Bridge Co., Ltd., Bay & Barton Sts., Hamilton, Canada.

CANTON

Ballard, E. L. (C), R. D. 7, North Canton, Ohio.
Klett, John J. (D), Republic Steel Corp., Massillon, Ohio.

CHICAGO

Magan, Thomas I. (B), Thomas Conlin Co., 450 Oakwood Blvd., Chicago, Ill.
Powell, Robert (D), 3500 N. Long Ave., Chicago, Ill.
Powell, William J. (D), 2501 N. Mason Ave., Chicago, Ill.

CINCINNATI

Hale, Robert S. (B), Room 1008, Atlas Bank Bldg., Cincinnati, Ohio.
Hoffman, Ray (D), R. R. 1, Hamilton, Ohio.

CLEVELAND

Barnes, Raleigh H. (C), American Steel & Wire Co., Rockefeller Bldg., Cleveland, Ohio.
Beal, W. (D), 224 W. Bridge St., Elyria, Ohio.
Canfield, Lee (C), 1002 Englewood Road, Cleveland Heights, Ohio.
Champion, Robert (D), Champion Rivet Co., E. 108th & Harvard Ave., Cleveland, Ohio.
Cooper, Wm. E. (D), 12606 Lake Shore Blvd., Cleveland, Ohio.
Dalton, E. W. (C), 10507 Lake Ave., Cleveland, Ohio.
Dougherty, Ward (C), 1695 E. 85th St., Cleveland, Ohio.
Fleming, M. J., Jr., (C), Alcazar Hotel, Cleveland Heights, Ohio.
Jerome, Charles H. (C), 3457 W. 97th St., Cleveland, Ohio.
Johnson, Albert T. (C), Hotel Cleveland, Cleveland, Ohio.
Kennerk, Perry (D), Lincoln Electric Co., 12818 Coit Road, Cleveland, Ohio.
Landon, Wallace (C), 1730 Wickford Road, Cleveland, Ohio.
Mahony, Alfred (D), 3789 W. 138th St., Cleveland, Ohio.
Marek, Stephen J. (D), 3635 W. 47th St., Cleveland, Ohio.
Mayor, William P. (D), Lincoln Electric Co., 12818 Coit Road, Cleveland, Ohio.
Nixon, Hartsel (D), 204 Lodi St., Elyria, Ohio.
Smith, John (C), 1413 Regent Road, Wickliffe, Ohio.
Specht, Joseph, (B), 7801 Spaford Ave., Cleveland, Ohio.
Stern, Lee D. (C), 2995 Lincoln Blvd., Cleveland, Ohio.
Warkee, Arthur A. (C), The Linde Air Products Co., 628 Keith Bldg., Cleveland, Ohio.
Wight, John W. (C), 11444 Euclid, Cleveland, Ohio.
Zawitzke, G. A. (C), R. F. D. 3, Willoughby, Ohio.
Zeh, Ray (D), 12213 Iowa Ave., Cleveland, Ohio.

CONNECTICUT

Fresher, George S. (B), Presto Battery Service, 106 Chapel St., Hartford, Conn.
Horelick, Michael (D), Dorr Co., Inc., Westport, Conn.
Rowland, Russell E. (C), Oxy Acetylene Supply Co., 394 Crown St., New Haven, Conn.
Welter, Gustave (B), The Bigelow Co., Box 706, New Haven, Conn.
Yuhasz, E. J. (C), Station 14, Windsor, Conn.

DETROIT

Fitzgerald, Robert (C), 6942 Jonathon, Dearborn, Mich.
Loveley, Joseph D. (C), 241 Glendale, Highland Park, Mich.
Neitzel, Henry C. (C), Whitehead & Kales Co., River Rouge, Mich.
Rennie, James (C), 12767 Purdue, Detroit, Mich.
Watt, Andrew M. (C), Champion Rivet Co., 403 Donovan Bldg., Detroit, Mich.
Wetherby, B. R. (C), Champion Rivet Co., 403 Donovan Bldg., Detroit, Mich.

HONOLULU

Woodside, Walter G. (C), The Island Welding Supply Co., Honolulu, T. H.

KANSAS CITY

Brian, J. K. (D), 3008 N. 30th St., Kansas City, Kansas.
Stubblefield, Walter F. (D), 204 E. Chestnut, Butler, Mo.

LOS ANGELES

Howard, Stephen L. (C), Box 113, Fellows, Calif.
Huffman, Shelton B. (D), 202 E. Cedar Ave., Bellflower, Calif.
Hughes, Paul B. (D), 1708 So. Soto St., Los Angeles, Calif.
Jones, J. J. (D), 4043 Acacia St., Bell, Calif.
Roberts, C. W. (C), Southwestern Eng. Co., 4800 Santa Fe Ave., Los Angeles, Calif.
Sorensen, W. C. (C), American Crystal Sugar Co., Box 562, Oxnard Calif.

MARYLAND

Bryan, Harry V. (D), 703 E. St., Sparrow Point, Md.
Wynn, Arthur R. (D), 2924 Northern Pkway., Baltimore, Md.

MILWAUKEE

Allen, Raymond (F), 521 E. State St., Milwaukee, Wis.
Ames, J. H. (F), 3352 N. Downer Ave., Milwaukee, Wis.
Barrett, A. C. (F), 2211 N. 23rd St., Milwaukee, Wis.
Bostrom, E. (F), Milwaukee School of Engrg., Milwaukee, Wis.
Dahl, Chester (F), 928 N. Water St., Milwaukee, Wis.
Dinges, George (F), 1120 N. Milwaukee St., Milwaukee, Wis.
Downing, Don (F), 1018 N. Milwaukee St., Milwaukee, Wis.
Eifler, Norman E. (F), 151 Hilbert St., Cedarburg, Wis.
Engevick, Elder (F), 521 E. State St., Apt. 21, Milwaukee, Wis.
Fent, W. D. (F), 1222 N. Van Buren St., Milwaukee, Wis.
Finley, H. J. (F), 828 E. State St., Milwaukee, Wis.
Gage, Walter (F), 521 E. State St., Apt. 21, Milwaukee, Wis.
General, August (F), 509 E. Knapp St., Apt. 18, Milwaukee, Wis.
Gollnick, Albert J. (C), 5520A N. 42nd St., Milwaukee, Wis.
Hellstern, Earl (F), 521 E. State St., Apt. 21, Milwaukee, Wis.
Holmberg, Herbert (F), 521 E. State St., Apt. 21, Milwaukee, Wis.
Huot, R. (F), 521 E. State St., Apt. 16, Milwaukee, Wis.
Johnston, Lester (F), 413 E. State St., Milwaukee, Wis.
La Chance, Mr. (F), 602 E. Juneau Ave., Apt. 16, Milwaukee, Wis.
Le Blanc, E. (F), 521 E. State St., Apt. 16, Milwaukee, Wis.
Marchinek, Fred E. (F), 521 E. State St., Apt. 21, Milwaukee, Wis.
Mayer, Clarence B. (F), 1222 N. Van Buren St., Milwaukee, Wis.
Neuser, C. (F), 521 E. State St., Apt. 21, Milwaukee, Wis.
Powell, M. E. (F), 1222 N. Van Buren St., Milwaukee, Wis.
Quilici, Joseph (F), 1806 W. Juneau Ave., Milwaukee, Wis.
Rydia, Arne (F), Route No. 2, Conneaut, Ohio.
Schreier, Henry (F), 1039 N. Milwaukee St., Milwaukee, Wis.
Schwerin, Herbert W. (F), 19 Jackson St., Cedarburg, Wis.
Sherman, James C. (D), 521 E. State St., Apt. 21, Milwaukee, Wis.
Sitzmann, Vernon (F), 521 E. State St., Apt. 21, Milwaukee, Wis.
Stafford, Robert T. (F), 1115 N. Jefferson St., Milwaukee, Wis.
Steinbach, L. (F), 521 E. State St., Apt. 20, Milwaukee, Wis.
Sushak, Joe (F), 1029 N. Van Buren St., Milwaukee, Wis.
Teisberg, Herman (F), Deerfield, Wis.
Wentworth, Howard (F), 521 E. State St., Apt. 21, Milwaukee, Wis.
Zahn, Otto, Jr., (C), Milwaukee School of Engineering, 1020 N. Broadway, Milwaukee, Wis.

NEW YORK

Adams, John (C), New York Trade School, 326 E. 67th St., New York, N. Y.
Cashmore, C. Ernest, Jr., (B), 812 Chestnut St., Roselle, N. J.
Lord, Arthur S. (B), National Inst., Inc., 1096 Broad St., Newark, N. J.
Mangon, Walter J. (B), 486 West 165th St., New York, N. Y.
Scott, Carlyle H. (B), Scott Welding Corp., 34-15 Bradley Ave., Long Island City, N. Y.
Sylvester, W. G. (C), 41 Gifford Ave., Jersey City, N. J.
Wheatley, John G. (C), Royal Indemnity Co., 150 William St., New York, N. Y.

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NEW PRODUCTS

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New Products Section

The Publications Committee has decided to include a New Products Section in the JOURNAL. We invite comments from our readers as to the value of such a section. We invite our manufacturers and others to promply advise us of their new products. The objective of including these items is service to our readers. The Publications Committee reserves the right to reject any items submitted. The Committee would like to include items of real interest and novelty.

Helmet

New onepiece seamless and rivetless welders' helmets and handshields equipped with Noviweld glass have just been announced by American Optical Company, Southbridge, Mass.

Features listed for the various models include non-slip handles; modern plate holders; improved headgear and pads; and lift-front lens handles, ideal for rapid inspection without removing helmet. Noviweld plate is in lift-front, and clear lens in stationary section protects eyes when lift-front is up.

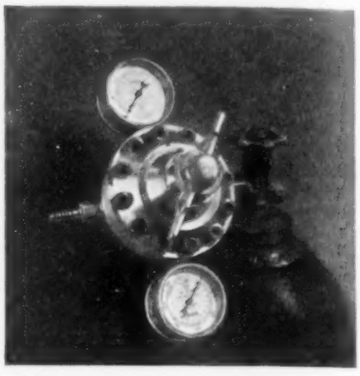
Diesel Engine Driven Arc Welder

A new diesel engine, which differs radically from the popular conception of this type of power in that it compares favorably with gasoline engines in simplicity, weight and cost, as well as operating speed, has been adopted for driving arc-welding generators by engineers of The Lincoln Electric Company, Cleveland, Ohio in collaboration with diesel engine manufacturers. Development of this new engine brings the economy of diesel operation to all applications of welding requiring engine driven arc-welding generators.

New 300-Ampere Diesel Engine Driven Arc Welding Set

Regulator

Particularly for oil refinery laboratories or wherever smaller volumes of extremely high delivery pressures are necessary, the new "GAS-O-DOME" regulator of the Victor Equipment Co., San Francisco, Calif., offers remarkable possibilities. This regulator is designed for working pressure ranges up to 5000 lb. psi and for primary pressures exceeding 5500 lb. psi.



The device can be furnished for remote control operation, which is of particular interest to many laboratories. The regulator illustrated is of the type which uses the primary pressure for delivery pressure control. Another one is produced utilizing a separate source of high-pressure gas (such as nitrogen) to actuate the diaphragm and this model can therefore be used for remote control.

Electrode for Welding Manganese Steel

The Harnischfeger Corporation of Milwaukee announces Smootharc "Harnang"—another in its long line of Smootharc welding electrodes. Designed for welding on parts subject to heavy impact, such as manganese castings railroad frogs and crossings, dipper teeth, etc., "Harnang" supplied the necessary toughness and hardness. Its base metal is nickel manganese steel, ranging from 11 to 14% nickel manganese, 3½ to 4½% nickel. Carbon content is in excess of 1%.

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Supplement to the Journal of the American Welding Society, April 1938

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Demolition Bombs

The Ordnance Department, U. S. Army, is investigating the manufacture of demolition bomb bodies by metallic arc welding. To be considered satisfactory, bomb bodies manufactured by this process must withstand impact on solid rock surfaces and/or armor plate, when released from the maximum altitude at which one-piece forged bomb bodies will withstand such impact.

The welding contemplated will involve the use of low-alloy steels. It must be of the highest quality and free from any defects which may impair the strength and impact properties of the welds or which may result in important stress concentrations in the welded structure. The bomb body must be stress relieved. Radiographic inspection and, possibly, magnaflux tests of the welds, under most rigid specifications, will be required. The workmanship must be equal or superior to that used in pressure vessel construction.

In order that the Ordnance Department may determine if the bomb bodies will meet the above requirements, a manufacturer must submit, without expense to the U. S. Government, eight (8) samples. One will be subjected to laboratory tests to determine the physical properties and quality of the welds, while the remaining bomb bodies will be available for dropping on solid rock surfaces and/or armor plate, as mentioned above. Manufacturers desiring to have their bids for manufacturing bomb bodies considered on proposals issued soon after July 1, 1938, must submit the samples for test prior to July 1, 1938. Thereafter, any manufacturer who has not previously qualified may submit samples at any time for test at the convenience of the Ordnance Department. Manufacturers who feel that they can meet the above requirements may obtain a circular outlining the requirements in greater detail by writing to the Office of the Chief of Ordnance, Washington, D. C.

Metal Deposition

In the January 1938 Supplement there was published an article by Professor Gilbert E. Doan on "Metal Deposition in Arc Welding." The process disclosed by the author under the above title was patented under No. 1,967,872.

Impact Symposium

A joint symposium on Impact Testing is being arranged in cooperation with A. S. T. M., the A. S. M. E., and the Welding Research Committee during the Annual Convention of the A. S. T. M. in Atlantic City the latter part of June. It is planned to distribute the papers in advance of the meeting, and reprints of the papers and discussions will be available in pamphlet form after the meeting. A tentative program is given below.

A. Basic Theory
1. The Work of Deformation to Fracture as Affected by Temperature, Velocity of Deformation and Form and Size of Notch, by D. J. McAdam, Jr., U. S. Bureau of Standards.
2. Stress-Strain Relations Under Impact Loading, by G. Dätwyler and D. S. Clark.
3. Speed Effects in Tension Testing at High Speeds: The Transition Velocity. Summary of results obtained at Watertown Arsenal, by H. C. Mann.

B. Present Day Uses of Impact Testing
1. An Argument for Utility Impact Testing, by Sam Tour.
2. The Charpy Test and Plastic Materials, Bell Telephone Laboratory.
3. Practical Applications of the Notched-Bar Impact Test, G. C. Riegel, Chief Metallurgist and F. F. Vaughn, Ass't. Chief Metallurgist, Caterpillar Tractor Co.

C. Impact Tests on Welded Specimens
1. Use of the Charpy Test as a Method of Evaluating Toughness Adjacent to Welds, by Walter H. Bruckner, formerly Bureau of Engineering, U. S. Navy (now University of Illinois).
2. Variable Speed Tension Impact Tests on Welded Specimens, by W. R. Warner, Watertown Arsenal.
3. Variable Temperature Tests on Welded Specimens, by Professor Henry, Brooklyn Polytechnic Institute—Probably.
4. Critical Digest of Impact Tests on Welds, by W. Spraragen and Dr. G. E. Claussen, Welding Research Board.

D. Summary
1. Impact Testing—A Summary, by S. L. Hoyt, A. O. Smith Corp.

Fatigue Research

A comprehensive program of Fatigue Testing of Large-Size Welded Specimens is now being formulated and will be started very shortly at the University of Illinois under the guidance of Professor W. M. Wilson. The work is in charge of an eminent committee of structural engineers and fatigue testing experts headed by Jonathan Jones, Chief Engineer, Fabricated Steel Construction, Bethlehem Steel Company. About $25,000 has already been pledged. The program includes for the first year studies on the Effect of Rest and information on Unit Design Stresses for Butt and Fillet Welds. In the joints having fillet welds, there will be side fillet, end fillets, and combinations of the two. After these unit design stresses are obtained for loads varying from zero to maximum, and reversal of stresses, the program will be continued to include different types of joints used in structural and bridge work.

This program has been made possible by cash contributions from the Chicago Bridge and Iron Works, and the U. S. Bureau of Public Roads. It is expected that the U. S. Navy and the American Institute of Steel Construction will also

Continued on page 32

THERMAL STUDY OF ARC WELDING

Experimental Verification of Theoretical Formulas*

By

D. ROSENTHAL, ING. A. I. Br., Dr. Sp.†

and

R. SCHMERBER, ING. A. I. Br.‡

INTRODUCTION

AS THE technique of welding becomes more and more advanced the factors hitherto considered secondary become more and more important. Among these factors, the distribution of heat and temperature during welding is particularly important in view of the structural changes and shrinkage stresses to which it gives rise. The experimental investigations so far performed have revealed the thermal characteristics of the usual welding processes, such as gas, arc and atomic hydrogen.[1] However, these investigations have not clearly defined the factors upon which the thermal characteristics of each process depend.

The theoretical study made by one of the authors[2] has partly filled the gap. In arc welding it was shown that the two important factors are current, I and the speed of motion of the electrode in the direction of welding, V_s. Both factors are under the welder's control to a considerable extent. But the theoretical solution of the problem admits of approximations and simplifications. It has, therefore, been submitted to experimental verification, which is the subject of the present paper.

EXPERIMENTAL CONDITIONS

The experimental arrangements consist of: (1) the specimen, (2) the equipment for measuring the temperature at different points in the specimen and (3) the recording instruments.

1. *Specimen* (*Fig. 1A and Fig. 4A*)

The specimen is a plate of mild steel containing 0.066 C, 0.446 Mn, 0.1 Si, 0.024 S, 0.082 P, and having a tensile strength of 50,800 lb./in.[2] A bead of weld metal is deposited on the upper edge in a single pass and at as constant speed as possible. It was desired to secure a temperature distribution that did not vary across the thickness.[3]

2. *Temperature Measurement*

Since the maximum temperature to be measured was 800° C., iron-constantan thermocouples were used (5 millivolts per 100° C.). The wires were 0.004 or 0.008 inch diameter, in order that thermal inertia would be as small as possible.[4]

Special precautions were taken in attaching the couples to the specimen. Electrical contact between couple and specimen could not be permitted in view of the method of recording the measurements that was used (see Appendix). The hot junctions were coated with a thin layer of refractory and inserted in holes 0.06 inch diameter drilled in the specimen, Fig. 1. To prevent contact of the wires with the specimens or among themselves, they were strung through quartz tubes. The method of attaching the couples to the specimen is shown in Fig. 1.

The insulation of the hot junction slows down the response of the couple. The effect was evaluated by quickly immersing a bare couple and a couple coated with refractory into media of different thermal conductivity but at the same temperature. A furnace maintained at 620° C. and a liquid bath maintained at 595° C. were used. The time taken by the couples in passing through

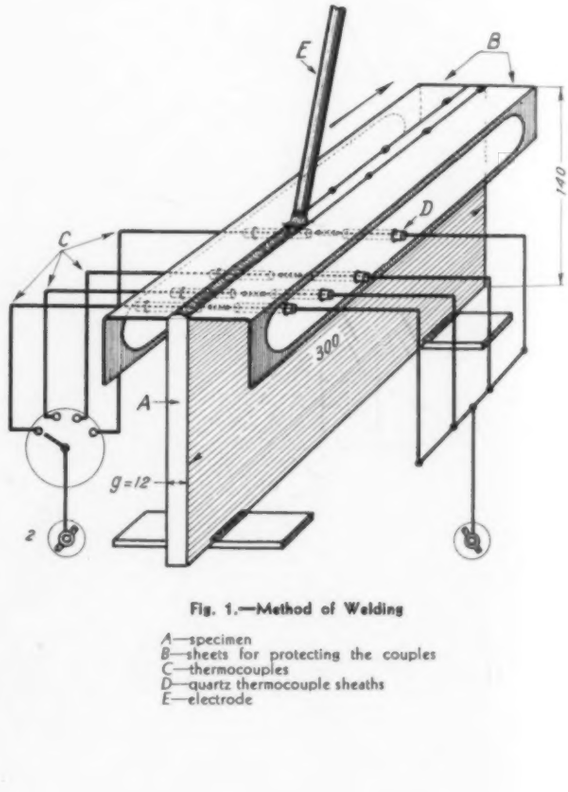

Fig. 1.—Method of Welding

A—specimen
B—sheets for protecting the couples
C—thermocouples
D—quartz thermocouple sheaths
E—electrode

* Prepared especially for the Fundamental Research Division, Welding Research Committee and translated by G. E. Claussen.

† Professor, Université Libre de Bruxelles, Brussels, Belgium.

‡ Electrical Engineer, S. A. Arcos, Brussels, Belgium.

1. A bibliography is given in Temperature Distribution During Welding. A Review of the Literature by W. Spraragen and G. E. Claussen, AMERICAN WELDING SOCIETY JOURNAL, **16** (9) Research Supplement 4–10 (1937).

2. D. Rosenthal, *Étude théorique du regime thermique pendant la soudure à l'arc, 2ème Congrès National des Sciences*, Brussels, 1935.

3. Preliminary tests were made with plates thinner than 1/2 inch, the welding being performed as shown in Fig. 2. Contrary to expectations, there were large variations in temperature through the thickness and the thinner plates were not used.

4. New thermocouples were used for each experiment. A standard couple was prepared from the same spools of wire from which the couples were made. The standard couple was used for calibration.

Table 1—Evaluation of the Inertia of the Thermocouples

Couple	Source of Heat	Interval of Temperature, ° C.	Time, Seconds	Velocity, ° C. per Sec.	Average Velocity	Delay, %
Bare	Furnace atmosphere at 620° C.	20 to 315	3.25	91		
Bare	Furnace atmosphere at 620° C.	20 to 410	4.0	97	93	
Bare	Furnace atmosphere at 620° C.	20 to 510	5.4	91		
Protected	Furnace atmosphere at 620° C.	20 to 315	3.95	75		
Protected	Furnace atmosphere at 620° C.	20 to 410	4.65	83	76.5	17.7
Protected	Furnace atmosphere at 620° C.	20 to 510	6.85	71		
Bare	Liquid bath at 595° C.	40 to 315	1.56	176	180.5	
Bare	Liquid bath at 595° C.	40 to 410	2.0	185		
Protected	Liquid bath at 595° C.	40 to 315	2.0	138	140	22.5
Protected	Liquid bath at 595° C.	40 to 410	2.6	142		

different ranges of temperature is shown in Table 1. Evidently the delay in % due to the coating on the couple increases only slightly as the thermal conductivity of the medium is increased. The average delay is 20%, within the limits that were tested.

Assuming that the conductivity of mild steel is not greater than that of the liquid bath, it may be concluded that the protected couple will follow faithfully only rates of change of temperature less than 140° C. per sec. On theoretical grounds, it is believed that the rate of change of temperature may exceed 140° C. per sec. in the vicinity of the source of heat (the electrode). For the sake of precision, therefore, the couples had to be placed at some distance from the weld metal. Besides, if the thermocouple hole is drilled too near the edge to be welded,

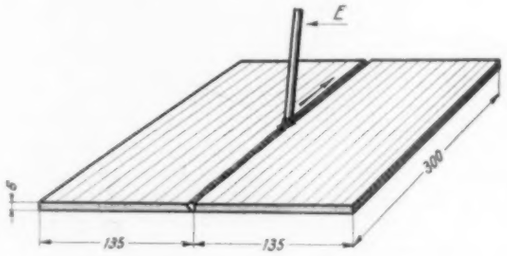

Fig. 2.—Sheet Specimen Used Only in Preliminary Tests

there is a large difference in temperature between the upper and lower edges of the hole.[5] Consequently slight differences in the way the couple rests in the hole may give rise to large errors. For these two reasons the temperature was never measured closer than 0.20 inch from the welded edge.

The couples are located by a system of coordinates, x and y, Fig. 3. The origin of the axes is about 1 inch from the start of welding. Its exact position is determined from the records described in the following section.

3. *Recording Instruments*

The voltages and currents created in a thermocouple are too weak to be recorded directly. A special amplifying tube was used (see Appendix), the amplified thermocouple current being delivered to a loop oscillograph, which yields a photographic record, Fig. 5. Time is recorded as abscissa by moving the plate at a uniform horizontal speed. Thus, the variation of temperature at each couple as a function of time during welding is recorded on a single photographic plate, Fig. 5.

5. For instance, in one of the tests Fig. 6 *B*, the difference amounted to: 80° C. at a distance of 0.16 inch from the welded edge; only 25° C. at a distance of 0.47 inch from the welded edge.

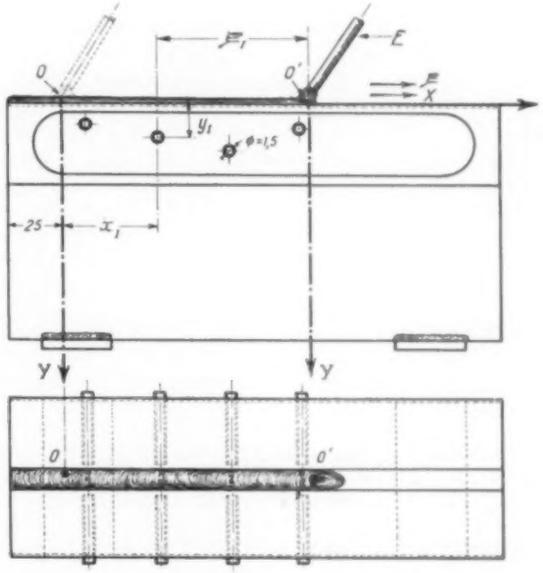

Fig. 3.—Location of Thermocouples
O—origin of coordinates x, y
O'—origin of coordinates ξ, y, referred to the electrode

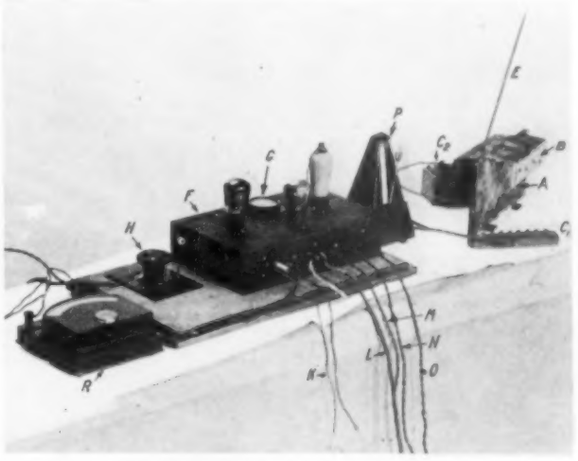

Fig. 4—Complete Experimental Arrangement
A—specimen
B—sheets for protecting the couples
C_1 C_2—thermocouple terminals
E—electrode
F—amplifier
G—milliammeter
H—commutator
K—to the oscillograph
L—to battery P
M—to high-voltage battery
N—to grid bias battery
O—to heating battery (for tube filaments)
P—metronome
R—millivoltmeter for calibration

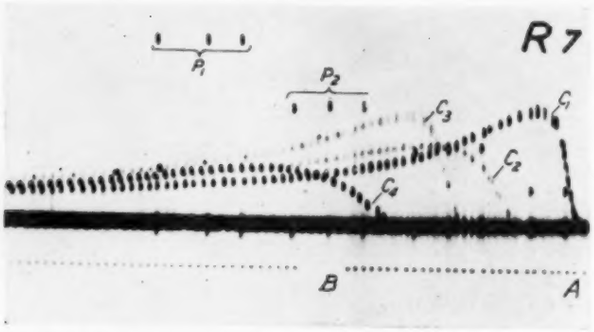

Fig. 5.—Diagram of Temperature as a Function of Time Recorded by the Oscillograph
A—start of recording time
B—end of welding
C_1 C_2 C_3 C_4 —temperatures measured by the thermocouples
P_1 P_2 —series of three dots for calibration

A special circuit was connected with the amplifier to register the temperature in terms of millivolts supplied to the amplifier. The entire experimental arrangement is shown in Fig. 4. A detailed description of each piece of apparatus is given in the Appendix.[6]

EXPERIMENTAL METHOD

The welding was done with a single phase transformer and a covered electrode 0.128 inch diameter, which melted uniformly and was particularly adapted to maintain a constant speed of advance. Arc voltage, V and current, I were measured in preliminary tests. The speed of motion of the electrode in the direction of welding, on the other hand, was determined in the course of each test. For this purpose the time taken by the electrode in traveling the distance between the origin O of coordinates x, y, Fig. 3 and the end of the bead was recorded on the photographic plate. Point A in Fig. 5 corresponds to the time the electrode passed O. Point B in Fig. 5 is the end of welding represented by the interruption in the row of dots. The speed of advance of the electrode, V_a, is easily calculated from these measurements.[7]

Knowing V_a, the distance, ξ, of the electrode from the origin[8] at any instant could be calculated, Fig. 3. The position of the electrode and the temperature recorded by each of the four thermocouples could be correlated, Figs. 1, 4 and 5. The set of points (ξ, y) representing the same temperature T constitutes the isotherm corresponding to that temperature. A family of isotherms is obtained for each specimen, Figs. 6 and 7. For convenience the scale of D is 4 times smaller than the scale of y.

Basically, the isotherms show the effect of speed of advance of the electrode, V_a, and the current, I on the temperature distribution. As a matter of fact, it was not feasible to vary one of these factors at will and maintain the other factor constant without adverse effects on the welding.[9]

Of eleven tests that were made, only those shown in Table 2 were satisfactory from the experimental point of view. The specimens were 300 mm. (11.8 inches) long, 140 mm. (5.5 inches) wide, and 12 mm. (0.47 inch) thick.

TEST RESULTS

The isotherms of the seven specimens are shown in Figs. 6 *A* and *B*, and 7 *A* and *B*. The results for specimens *L* 2 and *L* 3 on one hand and of *R* 6, *R* 7 and *R* 10 on the other, are practically identical. Differences of about 5% in the speed of motion of the electrode are reflected in the scatter of the experimental points and are considered as errors of measurement.[10]

The locus of points on the plate passing through the maximum temperature at the same instant is given by line O^1C in Figs. 6 *A* and *B*. To the right of this line is the zone of heating; to the left is the zone of cooling of the specimen. Comparison of Fig. 6 *A* with Fig. 7 *B* shows the influence of the factors that were varied.

INTERPRETATION OF RESULTS

In order to place the experimental results in accord with theory, let us briefly restate the problem.[11]

1. *Dimensions of Specimen*

Strictly speaking, the theoretical solution applies only to metallic plates of infinite length and width across which a point source of heat (very thin electrode) is traveling at constant velocity, V_a.[12] In order to approach the condition of infinite plates, the heating must

6. The system of amplifier and oscillograph was also used by H. Bornefeld, Dissertation, *Technische Hochschule*, Berlin, 1932.
7. A stop watch was also used to measure the time interval. The two methods of measurements usually were in agreement to within one second.
8. For relatively low temperatures this origin was outside the specimen.
9. The arc voltage V, as well as current I, play a part in temperature distribution. In the present experiments the arc voltage was maintained practically constant at 25 volts.
10. The probable mean errors in the isotherms are:
(*a*) for temperature, ±0.5 mm. vertical displacement of the spotof light = 13° C.
(*b*) for y, ±0.5 mm.
(*c*) for x, ±0.1 mm.
(*d*) for speed V_a, ±0.1 mm./sec.
(*e*) for time T, ±0.5 sec.
The mean error deduced for $\xi = x - V_a$: S = 100 mm. and V_a = 4 mm./sec., about 5 mm.; that is, 5%.
11. For more details see D. Rosenthal, loc. cit.
12. The point source has a bearing on the experimental results which will become evident later.

Table 2—Experimental Data

Specimen	Arc Voltage, *V*	Current, Amps.	Speed of Advance of Electrode, Mm./Sec.	Location of Couples, Figs, 1 and 3 Couple I X, Mm.	Couple I Y, Mm.	Couple II X, Mm.	Couple II Y, Mm.	Couple III X, Mm.	Couple III Y, Mm.	Couple IV X, Mm.	Couple IV Y, Mm.
L 2	25	93	2.02	25	6.5	78.5	8.0	52	12	105	19.5
L 3	25	93	2.17	25	6.0	78	8.0	52	12	105	19.7
R 7	25	141	4.32	25	6.0	125	8.0	75	12	176	19.5
R 10	25	141	4.41	25	4.0	75	6.0	125	10	*	*
R 6	25	147	4.10	24.5	6.0	125	8.0	75	12	174	20
R 8	25	141	8.9	25	5.5	125	8	75	12	175	20.5
R 9†	25	93	1.9	25	5.5	125	8	75	12	176	20.5

* Couple short circuited.
† The electrode was moved from side to side (weaving).

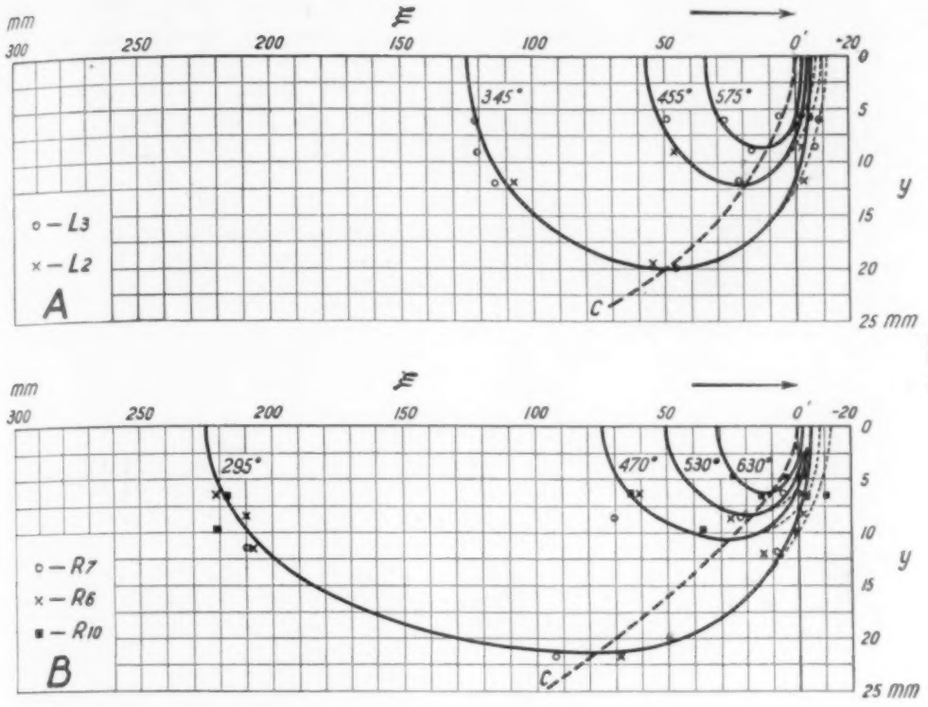

Fig. 6.—Isotherms
Full lines—calculated
Dotted lines—experimental
A—I = 93 amps., V_a = 2.10 mm./sec.
B—I = 141 amps., V_a = 4.30 mm./sec.

be confined to a small fraction of the plate. Figures 6 and 7 show that in the present tests, this fraction did not exceed $^1/_3$, which is a sufficiently good approximation to theoretical conditions.

2. *Quasi—Stationary Thermal State*

The theoretical solution is valid only in those regions of the plate which have attained the so-called quasi-stationary state, which is characterized by the fact that to an observer moving with the source of heat, the distribution of temperature around the source does not change with time.

The establishment of the quasi-stationary state can easily be demonstrated by means of the zones of different color, which form on the polished surface of a steel plate during welding. As we know, these colors are formed at definite temperatures so that the maximum temperature reached by different parts of a plate can be determined. When the thermal state is quasi-stationary, these zones become parallel to the direction of welding, Fig. 8. Observation of these zones of color in preliminary tests

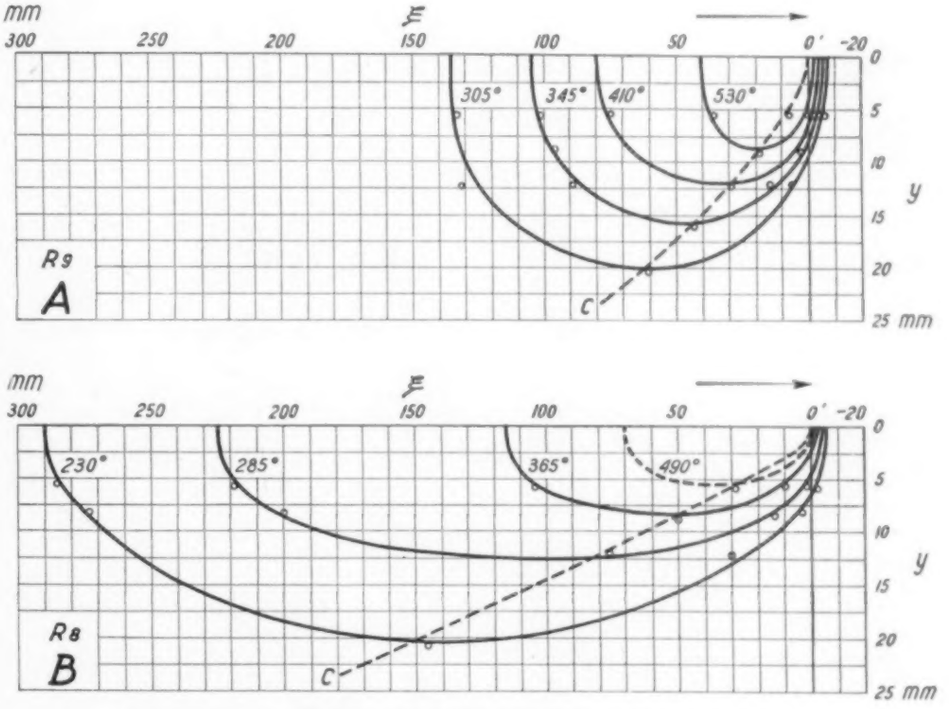

Fig. 7.—Experimental Isotherms
A—specimen R 9 (weaving), I = 93 amps., V_a = 1.9 mm./sec.
B—specimen R 8, I = 141 amps., V_a = 8.9 mm./sec.

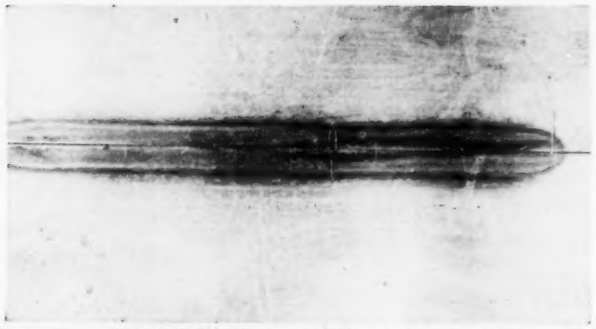

Fig. 8.—Zones of Oxide Colors Showing Establishment of the Quasi-Stationary State

showed that in our specimens the quasi-stationary state is established along the four lines representing the thermocouples before the electrode reached the origin of coordinates, O in Fig. 3.

3. *Validity of the Solution*

For the above reasons the experimental arrangements had to be such that the temperature was constant across the thickness of the plate. In this case the theoretical solution is of relatively simple form, if the system of coordinates in Fig. 9 are used. Symbols:

t_0 — ° C. = initial temperature of plate
t — ° C. = the temperature of any fiber PP′ during welding
r — Mm. = the distance of this fiber from the electrode, which is considered as a point source of heat
ξ = projection of r on the trajectory of this point source of heat.
g — Mm. = plate thickness
c — cal./gm. ° C. = specific heat of the plate
δ — gm./cm.^{3} = density of the plate
κ — cal./cm./° C./sec. = coefficient of thermal conductivity of the plate
$\kappa/c\delta = 1/2\lambda$ = cm.^{2}/sec. = coefficient of thermal diffusivity of the plate
q — cal./sec. = heat output of the source of heat.

The temperature t in each fiber PP' of the plate is given by the expression:[13]

$$t - t_0 = q \cdot e^{-\lambda \cdot V_a \cdot \xi} \cdot K_0 (\lambda V_a r)/\pi\kappa g \qquad (1)$$

In this expression, e is the base of naperian logarithms, and K_0 is a Bessel function of second kind and zero order. The value of this function can be calculated with the aid of Tables of Bessel functions.[14]

13. An analogous expression was found later by N. S. Boulton and H. E. Lance Martin; see bibliography in American Welding Society Journal, loc. cit.

14. When $\lambda V_a r$ is greater than 4, formula (1) can be replaced by:

$$t - t_0 = q \cdot e^{-\lambda V_a(\xi + r)}/\pi\kappa g\sqrt{\pi/2\lambda V_a r}$$

with an approximation accurate to 0.1%.

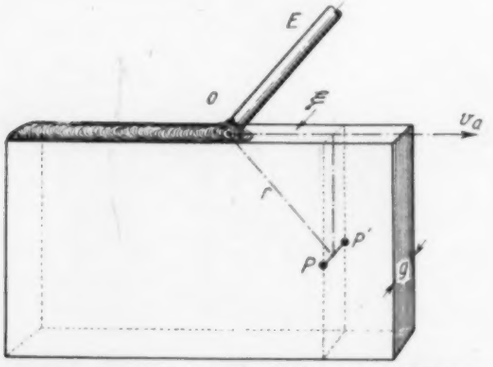

Fig. 9.—System of Coordinates (ξ, r) Adopted in the Calculations

Solution (1) *neglects* the loss of heat from the plate to the surrounding air. Furthermore, solution (1) presupposes that κ and λ are constant. The relatively thick plates used in our tests (0.47 inch) make the first assumption admissible. On the contrary, with mild steel, there is no basis for the supposition that κ and λ are constant. For example, Fig. 10 shows the variation of these coefficients with temperature in pure iron.[15] In the range of temperature from 200 to 800° C., the variation of the two coefficients, especially λ, is considerable. In its present state the theory is unable to take rigorous account of these variations.

Nevertheless, as we shall see, the theory can be made to agree with experiment by adopting the correct value of λ from Fig. 10 for each isotherm represented by formula (1) and assuming κ = constant.

Experimental Verification of Formula (1)

By means of the above method of calculation, the isotherms shown as full lines in Fig. 6 A and B have been

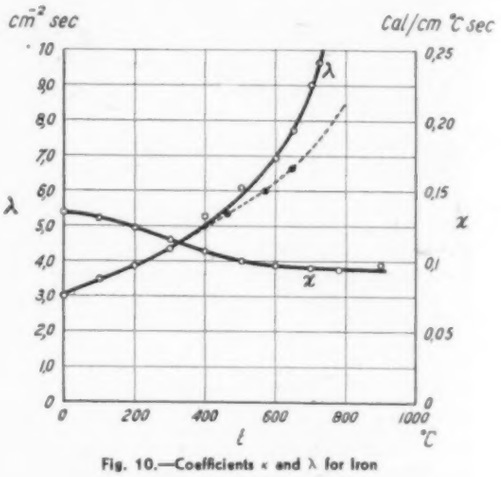

Fig. 10.—Coefficients κ and λ for Iron

obtained for the first five specimens in Table 2. The values of λ substituted in the formula (dotted curve, Fig. 10) are a little different from those for pure iron. The value of κ was assumed to be 0.1 and was the same for all isotherms. Formula (1) applied to each isotherm gave as the mean value of the heat output of the source of heat:

350 cal./sec. (± 6%) for specimens L 2 and L 3
538 cal./sec. (± 1%) for specimens R 6, R 7 and R 10.

The fact that these heat outputs are directly proportional to the welding current (93 and 141 amps.) will be discussed later.

Comparison of the experimental isotherms with the calculated, Fig. 6 A and B, reveals satisfactory agreement beyond a distance of 0.24 to 0.32 inch from the source of heat. However, close to the source the calculated isotherms are steeper than the experimental, which is a result of the assumption that the electrode was a point source of heat. When the distance r, Fig. 9, becomes of the same order as the diameter of the electrode, solution (1) must be replaced by a more exact solution taking account of the finite dimensions of the electrode.

The same calculation applied to specimens R 8 and R 9, Table 2, produced results in complete disagreement with experiment. Futhermore, q, instead of remaining con-

15. Drawn from information in Metals Handbook, 1933 Edition, American Society for Metals.

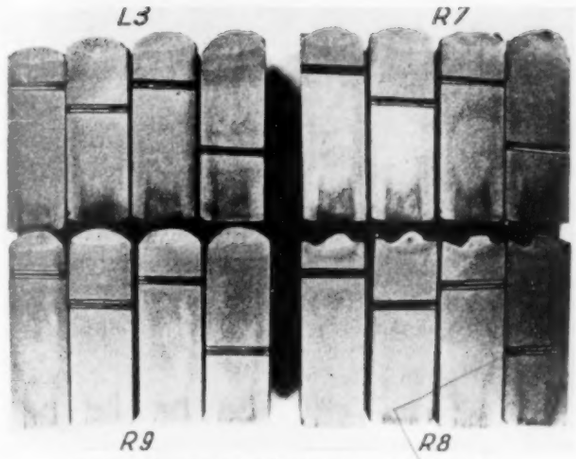

Fig. 11.—Cross Sections of Specimens *L* 4, *R* 7, *R* 9 and *R* 8

stant for the same specimen, had a different value on each isotherm. Consequently formula (1) does not apply to these two specimens. The reason is found in the appearance of the welds. Cross sections of the specimens, Fig. 11, show that as a result of the high speed of the electrode in specimen *R* 8, the bead did not extend over the entire edge of the plate. The temperature distribution was entirely different from those in specimens *L* 3 and *R* 7 and formula (1) does not apply.

Examination of sections of specimen *R* 9 reveals nothing unusual, but the weld was made by weaving the electrode. In weaving, the electrode stops at each edge. Therefore, there is an unusually large concentration of heat at the edges. The couples in the interior of the specimen register too low a temperature, lower than the average temperature of fiber PP'. As a matter of fact, for the same current and a still slower speed of advance of the electrode, the temperature of the plate appeared to be lower than that of specimen *L* 3. Practical experience proves the contrary.

The example of specimens *R* 8 and *R* 9 shows the utility of the theoretical studies without which discrepancies and anomalies encountered in the tests would be difficult to explain.

QUANTITY OF HEAT DELIVERED BY THE ARC TO HEAT THE SPECIMENS

If the power factor of the arc (nearly unity) is neglected, the quantity of heat set free by the arc per unit time is (V = volts; I = amp.):

$$Q = 0.239\ V \cdot I \text{ calories} \qquad (2)$$

where 0.239 is the thermal equivalent of electrical watts. A comparison of the arc heat so calculated with the amount of heat delivered to the specimen has been made in Table 3.

Table 3—Comparison of Arc Energy with Heat Delivered to Specimen

Volts	Current, Amps.	V_a	Q Cal./Sec.	q Cal./Sec.	q/Q
25	93	2.17	552	350	0.632
25	141	4.41	840	538	0.64

Table 3 shows that the majority of the heat given out by the arc heats the specimen. Doubtless the chemical reactions of the coating must modify the heat balance. Notwithstanding, the ratios 0.632 and 0.64, Table 3, are close to the ratio 0.65 calculated from the quantity of heat lost by the electrode in radiation and volatilization (see D. Rosenthal, loc. cit.). Table 3 also shows that the thermal efficiency of welding does not depend on current or speed of the electrode. The thermal efficiency appears to be in some way a characteristic constant of the process.

CONCLUSION

The experimental study of the thermal distribution in arc welding shows that the theoretical formula deduced by one of the authors is in satisfactory agreement with experiment within the limits of application of the formula. The agreement between calculation and experiment has been established only for the plane state; that is, the temperature is constant across the thickness of the specimen. Nevertheless, it may be presumed that the formula will apply as well to the more general case in which the temperature is not constant across the thickness. For it has been shown (D. Rosenthal, loc. cit.) that the formula for the plane temperature distribution during welding is only a particular solution of the triple state of that distribution.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance given by the Société Arcos, Brussels, Belgium, in the performance of the tests.

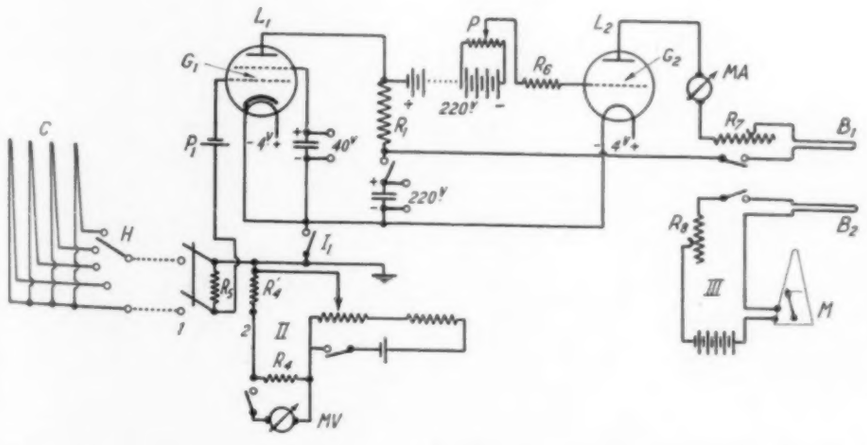

Fig. 12.—Circuit Diagram of Amplifier and Auxiliary Apparatus

C—iron—constantan thermocouples
1—switch points for making measurements
2—switch point for calibration
P_1—grid bias battery—1.5 volts
P—rheostat (20,000 ohms.) for adjusting the voltage from battery P
R_1—anode resistance = 200,000 ohms.
R_6—stabilizing resistance = 1000 ohms.
R_5—resistance (2000) ohms, for avoiding short circuit when the commutator (switch) is turned
I—potentiometric calibrating circuit
II—calibrating circuit itself with millivoltmeter for control
R_7—rheostat for adjusting the amplitude of loop B
III—timing circuit
R_8—rheostat for adjusting the amplitude of loop B_2
M—metronome
MA—milliammeter for control of amplification
H—commutator
MV—millivoltmeter

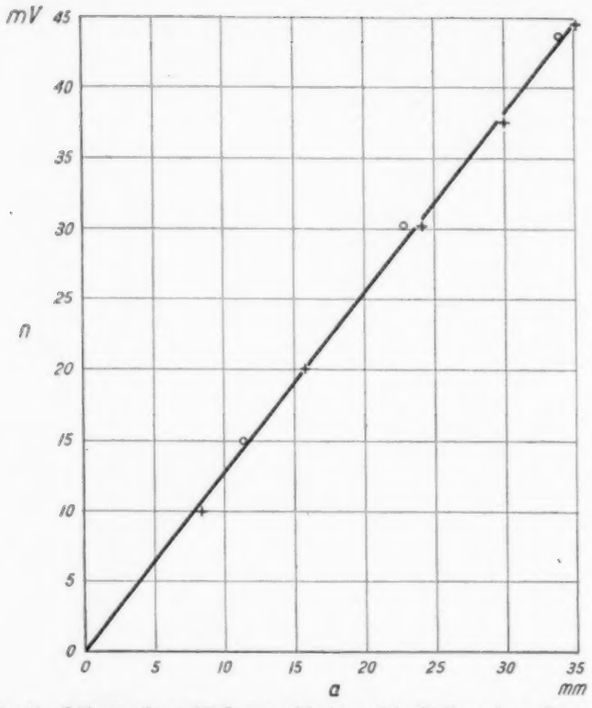

Fig. 13.—Calibration Curve of Deflections of the Loop of the Oscillograph as a Function of Millivolts, *n*, Applied to the Amplifier for Specimens *L* 2 and *L* 3

APPENDIX

Two problems arose in recording measurements from four thermocouples on the same photographic plate during welding. First, the changes in temperature were too rapid to be followed by an ordinary galvanometer, especially in switching from one couple to another. Second, the currents of a few microamperes produced by the couples were too weak to actuate the loop of the oscillograph that was available. Besides, the resistance of the loop was only one ohm; that of the couples was 25 to 50 ohms. A direct connection between loop and couple would have constituted a short circuit from the standpoint of the couple and no motion of the loop would have been observed.

These problems were solved by inserting a D.C. amplifier between the couples and the oscillograph, Fig. 4 (*F*) and Fig. 12. The change in voltage applied to the grid G_1 of tube L_1, which has four electrodes, Fig. 12, causes a change in voltage across resistance R_1, in series with the tube, which increases as the resistance is increased.[16] Since grid G_1 is connected to the couples C, the millivolts created by the latter are amplified about 100 fold across resistance R_1.

In turn, the voltage changes across R_1 are reproduced by the grid of a second tube L_2[17] and cause changes in current which can be handled by loop B_1 of the oscillograph in series with tube L_2. A suitable choice of tubes L_1 and L_2 permits a practically linear relationship to be obtained, Fig. 13, between the voltages *n* created by the thermocouples and the displacements *a* of the loop, which are recorded on the photographic plate.

The amplifier is made complete by a calibration circuit II by means of which a known voltage can be applied to grid *G* 1 and the amplification can be controlled by the milliammeter (M.A.). The calibration of the amplifier is represented on the photographic plate, Fig. 5, P_1, P_2, by the different series of three points each located outside the observed temperature curves. Each series corresponds to a known value of the applied voltage, which is read on the millivoltmeter M.V.

There is also a special timing circuit consisting of a second loop of the oscillograph B_2 connected to a source of current through a metronome supplied with a contact finger and an adjustable resistance *R*. A series of dots corresponding to the number of beats of the metronome, which has previously been set to the desired speed, is thus recorded on the photographic plate as it moves horizontally at constant speed.

Insulation of the Thermocouples

The amplifier requires that the couples be insulated. The welding is done with 50 cycle A.C. and the specimen is the ground. If the couples made contact with the ground (the specimen) they would follow the alternating voltage and the output of the amplifier would be modulated correspondingly. Modulation was suppressed by coating the tips of the thermocouples with a refractory paste. The electrical stability of the entire experimental apparatus was increased by grounding the metal case of the amplifier set to the common point of the batteries, to the specimen to be welded, and to an external ground.

Oscillograph

The oscillograph was of standard type[18] and was equipped with a special photographic recorder. The photographic plate is moved horizontally very slowly at constant speed by means of a speed reducer connected to a phonograph motor. The constant velocity of the photographic plate was about 66 mm. per minute (2.6 inches per minute).

Recording the Measurements

In order to record successively on a single photographic plate the voltages furnished by the four thermocouples, a 4-way commutator *H*, Figs. 4 and 12, was inserted between the couples *C* and the amplifier. The commutator was actuated by hand. The curves showing temperature changes, Fig. 5, C_1, C_2, C_3 and C_4, consist of a series of dots. After a record has been made the plate is calibrated in millivolts, as explained earlier.

16. The detailed theory of three-electrode tubes is given by C. Gutton, *LaLampe à Trois Electrodes, Recueil des Conferences—Rapports de documentation sur la physique*, **5**, Paris (1924).

17. These changes are first situated in the best zone of potential for the grid. Battery *P* (see C. Gutton, loc. cit.) is inserted in the circuit for this purpose.

18. Siemens oscillograph, demonstration type, 450-cycle loop.

THE EFFECT OF NITROGEN ON THE Welding of Steel

A Review of the Literature to July 1937

By W. SPRARAGEN* and G. E. CLAUSSEN†

This report is prepared under the auspices of
THE LITERATURE DIVISION OF THE ENGINEERING FOUNDATION
WELDING RESEARCH COMMITTEE

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Summary

NITROGEN IN STEEL

ALL industrial steels contain a small amount of nitrogen which is derived probably from the melting atmosphere and remains dissolved in the steel during cooling and subsequent use. Open-hearth steels may contain as little as 0.0015% N_2 and up to 0.008% N_2. Bessemer steel may contain 0.01–0.03% N_2.

One tenth of one per cent of nitrogen raises the yield strength of electrolytic iron from 22,000 to 23,000 lb. per sq. in., raises the ultimate tensile strength from 38,000 to 40,000 lb. per sq. in. and lowers the percentage elongation from 48 to 35% in 2 inches. Quenching may reduce this ductility to practically zero.

NITROGEN PICK UP IN WELDING

The metal deposited by bare electrodes may contain 0.081 to 0.228% nitrogen; the average appears to be 0.10 to 0.15%. Covered electrode deposits may contain as little as 0.003% nitrogen and as much as 0.067%. A high-grade covered electrode deposit at present may be relied upon to contain not over 0.02% nitrogen. Cored electrodes deposit metal containing 0.065 to 0.120% nitrogen. Oxyacetylene welds contain 0.006 to 0.028% nitrogen. Atomic hydrogen welds have been found to contain 0.013 to 0.026% nitrogen, and carbon arc welds in a hydrogen atmosphere appear to contain 0.025 to 0.046% nitrogen.

FACTORS AFFECTING NITROGEN PICK UP

1. Composition of Welding Rod

Bare Electrodes

Increase in carbon content from 0.015 to 1.0 reduces nitrogen from 0.14 to 0.05; manganese in small amounts is not effective in reducing nitrogen content. Effectiveness increases with 1½ to 4% Mn. About 3½% silicon appears to lower nitrogen pick up. Nickel up to 5% appears to have no marked effect. Chromium and aluminum tend to favor nitrogen pick up.

Covered Electrodes

Carbon in coatings up to 10% is effective in shielding the weld metal from nitrogen contamination. Manganese in coatings is effective in reducing oxides but not nitrides. Silicon (no information). Nickel reduces nitrogen pick up. Vanadium reduces nitrogen pick up. Chromium (no information). Aluminum (no information).

Gas Welds

The nitrogen content of gas welds is so small that definite effects due to different alloying elements in the rods have not been detected with certainty. Available results suggest that carbon and nickel reduce nitrogen pick up,

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manganese has no effect, and high chromium content (25%) may increase the pick up.

2. Welding Atmosphere

Hydrogen is effective as an atmosphere in reducing nitrogen pick up in gas and arc welds.

3. Coatings

Coatings applied to the electrode may reduce the nitrogen content to 0.02% or less. Apparently all industrial coatings reduce nitrogen pick up.

As the thickness of the coating is increased the decrease in nitrogen pick up at first is rapid, but increasing the thickness beyond a critical thickness appears to have little effect. A thin coating of lime has no effect on the nitrogen pick up with mild steel electrodes.

4. Arc Length and Voltage

An increase in length of arc, other conditions remaining as nearly constant as possible, increases nitrogen pick up slightly.

5. Current and Diameter of Electrode

The welding current does not have much effect on nitrogen pick up.

6. Polarity

The polarity of the electrode has little effect on nitrogen pick up by the weld metal.

Type of Current

Coated electrodes deposited with alternating current appear to pick up more nitrogen than with direct current.

ORIGIN OF NITROGEN PICK UP

The vital factors are the form and volume of the nitrogen presented to the electrode and weld metal.

Pick up and retention of nitrogen increases with temperature, pressure of atmosphere, and increase in rate of cooling.

Coatings are effective in reducing nitrogen because they evolve gases which dilute the air around the arc, form in some cases compounds with nitrogen, and may in some cases reduce the temperature. Ionized nitrogen, such as from decomposition of ammonia, results in greater pick up than pure nitrogen or air.

METALLOGRAPHY

In 1911, B. Strauss found a needle-shaped constituent in arc welds containing 0.12% nitrogen. The needles are plates and during the annealing of welds the plates grow and oxide globules grow, but there are no intermediate forms between the nitrides and the oxides.

Furnace-cooled from a high temperature (1000° C.), high-nitrogen weld-metal exhibits a microstructure consisting of nitride needles distributed uniformly through the ferrite with areas of iron-iron nitride eutectoid, known as braunite, distributed somewhat like pearlite through the steel. Water-quenched from 700° C., the braunite in the high-nitrogen weld metal is replaced by nitrogen martensite. Samples water quenched from 900° C. consist entirely of nitrogen martensite.

The nitrogen content at which needles just appear in the microstructure of weld metal appears to depend, among other things, on the rate of cooling from above 600° C.

Annealing in hydrogen for 12 hr. at 1400° C. removed most of the nitrogen in a specimen originally containing 0.15% nitrogen.

The electric conductivity of bare electrode weld metal is decreased by water quenching from 600° C. but is increased during the course of time at room temperature. The oxyacetylene and atomic hydrogen welds showed practically no change.

MECHANICAL PROPERTIES

As weld-metal is difficult to obtain in a state of purity, expecially with respect to oxygen if the nitrogen content is high, many of the specimens used by investigators may be considered as high-oxygen, as well as high-nitrogen weld-metal. Consequently, there is some difficulty in deciding to which of the several impurities that may be present in a specimen of weld-metal may be attributed the characteristic properties of the metal.

The conclusions to be drawn from available information on the mechanical properties of welds of mild steel grade containing nitrogen are:

1. High-nitrogen (and high-oxygen) weld-metal (above about 0.03–0.05 N_2) in the untreated condition lacks the customary ductility of mild steel in the static tensile test at temperatures from 20 to 1000° C. The notch-impact value of high-nitrogen welds in mild steel is very poor (1 to 10 ft.-lb.). Low-nitrogen welds have impact values of 40 ft.-lb. or more (approximately the same as unwelded steel).
2. Water quenching from 600° C. or above, with or without aging (holding for a period of time) at room temperature, as well as artificial aging (about 10% strain at 20° C. followed by heating at 250° C.) seriously lower the ductility and notch toughness if the nitrogen content of the weld-metal exceeds about 0.04%.
3. Air cooling or furnace cooling from 600° C. or above has an adverse effect on notch-impact value in plain carbon welds although it may improve the static ductility. Such heat treatment appears to improve welds made with nickel steel rods.
4. High-nitrogen welds containing 2% nickel appear to have low notch toughness and static ductility but not to so great an extent as unalloyed deposits, nor are they as dangerously sensitive to water quenching.
5. Ductility and notch toughness can be imparted to high-nitrogen weld-metal only by removing the nitrogen, for example, by heating several days in hydrogen at 600 to 1000° C.
6. Welds with medium and high nitrogen show a decided decrease in unnotched-impact values at low temperature. The low-nitrogen welds, on the other hand, retain good unnotched-impact values even at −80° C.
7. Slight effects due to nitrogen appear to be produced in welds containing as little as 0.018% nitrogen.
8. Of the different microstructures appearing in high-nitrogen weld-metal, the needle structure appears to be more ductile than the martensitic (water quenched from above about 700° C.) and the supersaturated solid solution (water quenched from 550–600° C.).
9. Proof is lacking that the poor mechanical properties of bare electrode weld-metal are due to nitrogen alone or primarily. Other impurities and grain size exert powerful influences on the mechanical properties.
10. The welding of mild steel plate containing 0.03 C, 0.020 N may create a zone of lower strength than base metal in the region heated to 320° C. maximum during welding.

Effect of Nitrogen on the Welding of Steel

INTRODUCTION

In the early days of arc welding, nitrogen was one of the most important elements in the welding of steel. Nitrogen from the air contaminated the early bare electrode welds and made them brittle. Good gas welds were always relatively free from this contamination. With the adoption in recent times of covered electrodes for all important welds the nitrogen problem has disappeared almost entirely. Nevertheless, the best fusion welds nowadays still contain rather more nitrogen than is usual in open-hearth steel, and occasionally troublesome effects created by the absorbed nitrogen are observed in the heat treatment of covered electrode and gas welds. For this reason it is important to have a review of the literature concerning the origin of nitrogen in welds in unalloyed and low-alloy steel and the effects of nitrogen absorbed during welding on the structure and mechanical properties of the welds.

Since nitrogen is an impurity rather than an alloying element in steels, there is little information on the welding of "nitrogen steels." The welding of nitrided steels appears never to be done and, as Fry stated in 1929, there is even a problem in welding nitriding steels so that the junction will be perfectly hard after nitriding. The review of literature, therefore, is confined of necessity to weld metals containing nitrogen picked up from the welding atmosphere.

NITROGEN IN STEEL

All industrial steels contain a small amount of nitrogen which is derived probably from the melting atmosphere, and remains dissolved in the steel during cooling and subsequent use. Open-hearth steels may contain as little as 0.0015% N_2 and up to 0.008% N_2. Bessemer steel may contain 0.01–0.03% N_2, the amount increasing with time of blow and maximum temperature. According to Chipman, iron in equilibrium with nitrogen dissolves 0.04 weight % N_2 at 1600° C. Little is known about the removal of nitrogen from a melt of steel, but titanium and aluminum probably remove nitrogen as the corresponding nitride. The nitrides of silicon and manganese are too unstable.

The iron nitrides themselves are unstable at elevated temperatures, as shown by the equilibrium diagram, Fig. 1. Fe_4N decomposes at a little above 600° C. and Fe_2N decomposes above 500° C. in a nitrogen atmosphere at 760 mm. mercury. In the low concentrations of nitrogen usually found in welds (less than 0.2% N_2), nitrogen may occur in three forms: solid solution, nitride needle or eutectoid (Braunite) depending on nitrogen content and heat treatment. At relatively low rates of cooling, such as in still air from over 650° C., braunite is found with needles if the nitrogen content is above 0.1%, according to Séférian. The needles separate in the range of temperature between 590 and 200° C. and are present alone in steels containing between about 0.01 and 0.1%. Below about 0.01% the nitrogen remains in solid solution at all temperatures.

The effect of about 0.1% nitrogen on the mechanical properties of electrolytic iron is shown in Table A, prepared by Köster. The specimens containing needles are not much less ductile than electrolytic iron. The brittleness of the quenched specimen may be caused by aging at room temperature, the precipitate being sub-microscopic. Aging is usually complete in 1 to 10 hr. at 150° C.

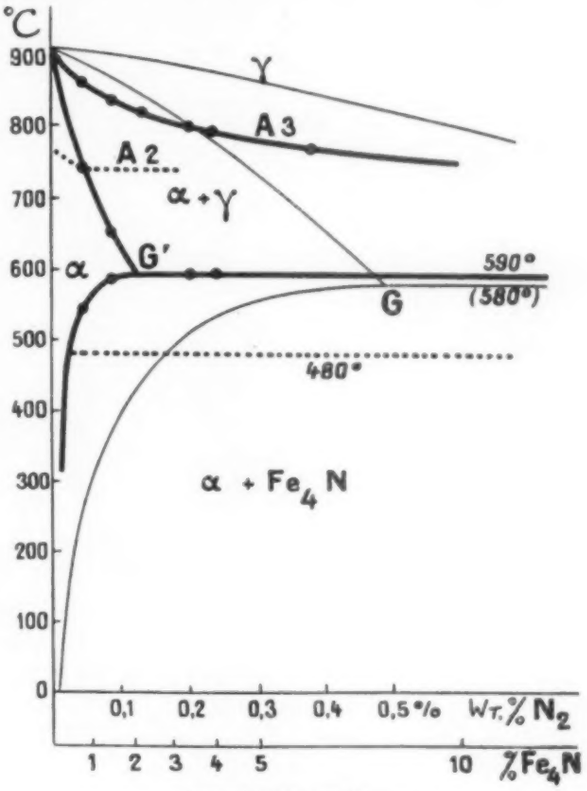

Fig. 1—Iron-Nitrogen Diagram
T = degrees Centigrade
Séférian (1936) in heavy lines and Fry (1923) in light lines

after which overaging occurs. At lower temperatures, such as 50° C., aging may not be complete after several weeks, depending on the nitrogen content. The aging of nitrogen is accelerated by cold work. For example, a Bessemer iron containing 0.021% nitrogen which shows very little microscopic evidence of aging after 1 hr. at 100° C., shows a profusion of minute nitride particles in cold hammered regions after the same heat treatment. By aging is meant the changes in properties that may occur during a period of time (time of aging) at room temperature or slightly above or below room temperature.

Table A—Mechanical Properties of Nitrided Electrolytic Iron. Köster (1930)

Specimen	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation %	Reduction of Area, Q %	Structure
Electrolytic iron	22,000	38,000	48	87	Ferrite
Nitrided and cooled in furnace	23,000	40,000	35	81	Ferrite + coarse nitride needles
Water-quenched from 550° C.	28,000	45,000	0	0	Ferrite with nitrogen in solid solution
Water-quenched from 550° C., heated to 250° C. and slowly cooled	24,000	45,000	30	80	Ferrite + fine nitride needles

NITROGEN PICK UP IN WELDING

The nitrogen content of different types of welds mainly in mild steel in air is shown in Table 1. The metal deposited by bare electrodes may contain 0.081 to 0.228%

nitrogen; the average appears to be 0.10 to 0.15%. Covered electrode deposits may contain as little as 0.003% nitrogen and as much as 0.067%. A high-grade covered electrode deposit at present may be relied upon to contain not over 0.02% nitrogen. Cored electrodes deposit metal containing 0.065 to 0.120% nitrogen. Oxyacetylene welds contain 0.006 to 0.028% nitrogen. Atomic hydrogen welds have been found to contain 0.013

Table 1—Nitrogen Pick Up in Welding

References	Weight % Nitrogen	Welding Conditions	Method of Analysis
Houston,[1] 1936	0.119	Electrode: 10 gage, 0.12–0.18 C.	
Larson,[2] 1936	0.15		
Gezov,[3] 1936	up to 0.2		
Moses,[4] 1935	0.10–0.15		
Reeve,[5] 1935	0.181		Vacuum fusion
		Bare Electrodes	
Lohmann and Schulz,[6] 1934	0.103–0.123	Electrode: 0.13 C, 0.35 Si, 0.68 Mn, 0.78 Cu, 0.38 Cr. Base metal (0.08–0.27 C; 0.01–0.60 Si; 0.45–1.04 Mn; 0.12–0.75 Cu; up to 0.47 Cr) had no effect. 60° V butt welds in plates.	
Ziegler,[7] 1932	0.093–0.127		Vacuum fusion
Schuster,[8] 1932	0.228	Armco electrode	Allen
Hodge,[9] 1932	0.125	Weld-metal: 0.014–0.023 C; 0.13–0.29 Mn	
Schoenmaker,[10] 1931	up to 0.15		
Fry,[11] 1931	0.084–0.130	Electrode: 0.04–0.08 C, up to 1.62 Mn, up to 0.12 Si. Single pass V welds in mild steel (0.11 C, 0.55 Mn, trace Si) 0.24 inch thick.	
Fuchs,[12] 1930	0.15		
A. R. E. E.,[13] 1926	0.11–0.13	Electrode: 0.16 C, 0.56 Mn, 0.016 Si.	
Viall,[14] 1921	0.10–0.15		
Rawdon,[15] 1921	0.094–0.156	Electrodes: 0.06–0.15 C; 0.002–0.004 N_2	
Paterson and Blair,[16] 1919	0.081–0.135		Ammonia-Zinc
		Covered Electrodes	
Woirin,[17] 1937	0.011	Average at Penhoët, France for boiler welds	
Hackert and Zeyen,[18] 1937	0.100	Cored alloy steel, 10 layers, 90° V, 0.79-inch plate	HCl solution
	0.098	Cored alloy steel, 3 layers, 60° V, 0.47-inch plate	
	0.036	Covered electrode A, 25 layers, 90° V, 0.79-inch plate	
	0.020	Covered electrode A, 6 to 6 layers, 60° V, 0.47-inch plate	
	0.026	Covered electrode C, 25 layers, 90° V, 0.79-inch plate	
	0.010	Covered electrode C, 5 to 6 layers, 60° V, 0.47-inch plate	
	0.025	Covered electrode D, 25 layers 90° V, 0.79-inch plate	
	0.013	Covered electrode D, 5 to 6 layers, 60° V, 0.47-inch plate	
Chatalbashyan,[19] 1937	not over 0.02		
Larson,[2] 1936	0.015		
Houston,[1] 1936	0.040	Electrode: 10 gage, 0.12–0.18 C	
Leitner,[20] 1936	0.021–0.067	Covered	Wüst & Duhr
	0.065	Cored (Zeyen[63] (1938) reports 0.11% N_2 in cored electrode deposit)	
Moses,[4] 1935	0.01–0.035		
Hoyt,[21] 1935	0.010	Cellulose covered	
Hiemke,[22] 1935	less than 0.035	Inorganic covered	
Lincoln,[23] 1935	not over 0.02		
Reeve,[5] 1935	usually 0.01–0.02 but as low as 0.003		Vacuum fusion
Lohmann and Schulz,[6] 1934	0.116–0.120	Cored	
	0.005–0.038	Covered	
Hodge,[9] 1932	0.015		
Hensel and Larsen,[24] 1932	0.029–0.056		Vacuum fusion
Schoenmaker,[10] 1931	up to 0.04		
Fry,[11] 1931	0.026–0.052	Dipped, single pass weld, asbestos covered, single pass weld cored,	
	0.038	single pass weld, electrode contained 0.07 C, 0.53 Mn	
	0.120		
Fuchs,[12] 1930	0.09	Dipped	
	0.05	Covered	
Mladiata,[25] 1926	1.26	No explanation	
		Oxyacetylene Welds	
Gezov,[3] 1937	less than 0.02	Armco rods	
Portevin and Séférian,[26] 1936	0.02	Armco rods 0.16 inch diameter	Gezov modification of Wüst and Duhr
Leitner and Schmidt,[27] 1936	0.020	(Needles were visible in microstructure; mild steel)	
Tichodeev,[28] 1936	0.007	Neutral flame; rods: 0.11–0.12 C, 0.20–0.28 Si; 0.36–0.46 Mn	
	0.006–0.0158	Oxidizing flame; rods: 0.11–0.12 C, 0.20–0.28 Si; 0.36–0.46 Mn	
Ziegler,[7] 1932	0.017		Vacuum fusion
Schuster,[29] 1932	up to 0.028	Oxidizing flame, commercial steel	Allen
Hensel and Larsen,[24] 1932	0.013		Vacuum fusion
	0.024		Beiter
Fry,[11] 1931	0.011–0.015	Rod: 0.04 C; up to 1.62 Mn; single pass weld	
Hoffmann,[30]	0.082	Rod: 0.10 C; 0.06 Si; 0.32 Mn	
		Atomic Hydrogen Welds	
Schuster[55]	0.020	Cracked ammonia gas; hand welded	Allen
	0.028	Hydrogen gas; hand welded; weld-metal contained 0.42 Mn	Allen
Tichodeev,[28] 1932	0.014–0.026	Rods: 0.11–0.12 C; 0.20–0.28 Si; 0.36–0.46 Mn	
Hensel and Larsen,[24] 1932	0.017	Weld contained 0.033 C; 0.15 Mn; 0.26 W	Vacuum fusion
Ziegler,[7] 1932	0.013		Vacuum fusion
		Carbon Arc Welds	
Tichodeev,[28] 1936	0.025–0.046	Hydrogen atmosphere; rods: 0.11–0.12 C, 0.20–0.28 Si, 0.36–0.46 Mn	

to 0.026% nitrogen, and carbon arc welds in a hydrogen atmosphere appear to contain 0.025 to 0.046% nitrogen. A thermit weld made in an atmosphere of carbon dioxide and examined by Goodger[31] was found to contain many nitride needles. Fry[11] observed characteristic nitrogen etch figures near the flame cut edge of a boiler plate, but the plate more likely obtained its nitrogen from the refining furnace than from the cutting torch.

FACTORS AFFECTING NITROGEN PICK UP

1. Composition of Welding Rod

Of the many factors that may influence the pick up of nitrogen, the composition of the welding rod has received the most attention in the literature.

Carbon

The pick up of nitrogen as a function of carbon content of electrodes is shown in Table 2, which summarizes the results of Portevin and Séférian.[26] The electrodes, which were of different diameters (no details), were deposited automatically in air, 0.12-inch arc, d.c. The coating was "neutral" and contained 47% Fe_2O_3, 41% SiO_2, 8% Al_2O_3, 3% Na_2O, loss in arc 1%. The current was maintained constant in all tests but the thickness of the coating and polarity were not stated. An increase in carbon content in the electrode was considered to reduce the nitrogen pick up.

Table 2—Nitrogen Pick Up as a Function of Carbon Content of Electrode. Portevin and Séférian[26]

Composition of Electrode			Composition of Deposited Metal					
			Bare Electrode		Thin Coated		Medium Coated	
C	Mn	Si	C	N	C	N	C	N
0.03	..	..	...	0.16	...	..	...	...
0.45	0.14	0.25	0.215	0.140	0.074	0.044	0.052	0.036
0.80	0.11	0.13	0.385	0.132	0.065	0.041	0.053	0.030

Much greater effects were observed by Hoffmann,[32] as shown in Table 3. The sulphur and phosphorus contents were fairly constant at about 0.015% each. In the absence of details, Hoffmann's results must be accepted with caution. Using a rod containing 0.08 C, 0.32 Mn, 0.06 Si, Losana[33] found that an increase in carbon content in the coating. a.c. welding, Table 4, decreased the nitrogen pick up (no details). Schuster[29] observed that bare Armco iron electrodes always deposited metal containing more nitrogen (0.23% as compared with about 0.15%) than bare mild steel electrodes. He also showed[8] that nitride needles tend to be inhibited as the carbon content is increased in iron containing nitrogen. On the other hand, Doan and Schulte[34] found that welds made in air with bare pure iron electrodes contained 0.098% nitrogen but that welds made with bare steel electrodes contained 0.172% nitrogen.

Table 3—Nitrogen Pick Up as a Function of Carbon Content of Electrode. Hoffmann[32]

Composition of Rod			Gas-Welded Deposit			Arc-Welded Deposit		
C	O	N	C	O	N	C	O	N
0.05	0.031	0.028	0.06	0.082	0.048	0.03	0.215	0.122
0.40	0.025	0.020	0.24	0.071	0.040	0.20	0.147	0.089
0.80	0.026	0.019	0.62	0.041	0.021	0.60	0.100	0.064
1.10	0.021	0.020	0.93	0.038	0.028	0.90	0.092	0.048

Table 4—Nitrogen Pick Up as a Function of Carbon Content of Coating. Losana[33]

Diameter of Electrode, Inch		Percentage Carbon in Coating						
		1	2	4	5	6	8	10
0.08	N_2	0.088	0.080	0.061	0.032	0.020	0.016	0.013
	O_2	0.120	0.062	0.034	0.030	0.028	0.030	0.027
0.16	N_2	0.040	0.041	0.021	0.012	0.009	...	0.008
	O_2	0.071	...	0.031	...	...	0.020	0.017
0.24	N_2	0.022	0.021	0.018	0.010	...	0.006	0.017
	O_2	0.06	...	0.024	...	...	0.014	0.008

Miller[35] found that as the carbon content of the bare electrode ($^5/_{32}$ inch diameter, 150 amps. in air, polarity not stated) is increased from 0.015 to 1.0%, the nitrogen content of the deposited metal decreased from 0.135 to 0.05%. Miller explained the decrease as a result of the shielding effect of the increasing proportions of CO and CO_2 evolved as the carbon content was increased. Rapatz[36] attributed the low gas content of high carbon weld metal (no details) to the reaction of carbon with oxygen and nitrogen to form CO and CN before the gases have the opportunity to be picked up by iron.

Manganese

Schuster[8] believed, on the basis of the results shown in Table 5 (no details), that manganese in small percentages tends to reduce the nitrogen content of bare electrode weld metal to a minimum of 0.08%. Portevin and Séférian[26] also found that the nitrogen content of bare deposits decreased from 0.12% nitrogen with a bare electrode containing 2% Mn to 0.07% N_2 with an electrode containing 5% Mn. Details of their work are not given and their electrodes contained 0.27 to 1.21 C.

Table 5—Nitrogen Pick Up as a Function of Manganese Content of Electrode. Schuster[8]

Composition of Electrode		Composition of Deposit			
		Electrode Positive		Electrode Negative	
C	Mn	N	Mn	N	Mn
0.09	12.95	0.140	10.5	0.143	10.5
0.06	3.95	0.080	2.09	0.062	1.76
0.09	1.68	0.082	1.54	0.098	...

The nitrogen content of single-pass V welds made by Fry[11] in mild steel (0.11 C, 0.55 Mn, trace Si, 0.24 inch thick) is shown in Table 6. According to Haardt,[37] the deposit of a bare electrode containing 3.5 Mn, 0.2 Si, 0.10 C contained 0.12%. Hodge[9] found that a change in manganese content from 0.13 to 0.29% had no effect on the pick up of nitrogen by bare electrode weld-metal in mild steel. Losana[33] found that an increase in manganese content in the coating ("neutral") of an electrode containing 0.08 C, 0.32 Mn, 0.06 Si decreased the nitrogen pick up in a.c. welding, Table 7 (no details) up to about

Table 6—Nitrogen Pick Up as a Function of Manganese Content of Welding Rod. Fry[11]

Composition of Welding Rod			Oxyacetylene Weld		Bare Electrode Weld		Dipped Electrode Weld	
C	Si	Mn	O_2	N_2	O_2	N_2	O_2	N_2
0.04	0.05	0.05	0.016	0.015	0.180	0.130	0.078	0.052
0.08	0.01	0.52	0.016	0.011	0.120	0.120	0.070	0.051
0.04	0.01	0.72	0.017	0.011	0.078	0.110	0.066	0.032
0.08	0.12	1.62	0.007	0.013	0.095	0.094	0.065	0.026

6% Mn for thin electrodes. With thicker electrodes or higher manganese content in the neutral coating the nitorgen pick up was increased.

Table 7—Nitrogen Pick Up as a Function of Manganese Content of Coating. Losana[33]

Diameter of Electrode, Inch		Percentage Manganese in Coating						
		2	4	6	8	10	20	30
0.08	N_2	0.102	0.098	0.090	0.108	0.121	0.158	0.189
	O_2	0.070	0.042	...	...	0.009	0.005	0.006
0.16	N_2	0.036	0.040	0.044	0.051	0.067	0.098	0.112
	O_2	0.058	0.030	0.018	...	0.006	0.006	0.005

Silicon

Schuster's[8] tests showed that silicon in bare electrodes decreases nitrogen pick up and increases the solubility of nitrogen in ferrite, as shown in Table 8. The electrodes were deposited on plates of the same composition as the electrode. With 0.25 Mn and about 0.12 C, Schuster

Table 8—Nitrogen Pick Up as a Function of Silicon Content of Electrode. Schuster[8]

Composition of Electrode			Composition of Deposited Metal: Electrode Positive				Electrode Negative				
C	Si	Mn	C	Si	Mn	N_2	C	Si	Mn	N_2	Nitrides
0.11	1.22	0.26	..	0.72	0.19	..	0.034	0.73	0.19	0.077	No needles
0.073	1.46	0.30	..	..	..	..	0.066	0.86	0.24	0.062	No needles
0.011	4.0	0.28	..	3.53	..	..	...	3.53	..	0.030	No needles

concluded that 1.1% Si was needed to suppress needle formation in any heat treatment. Haardt[37] found that a deposit from a bare plain-carbon electrode on a plate containing 0.1 C, 0.4 Mn, 3.85 Si contained only 0.07% nitrogen at 155 amp., which confirms Schuster's statement that silicon decreases nitrogen pick up. On the other hand, Portevin and Séférian[26] found that the deposit from a bare electrode containing 0.08 C, 0.13 Mn, 3.95 Si, contained 3.23 Si and 0.11% nitrogen. A new micro-constituent, which, it was supposed, may be a complex nitride, was found in the deposit.

Nickel

The effect of nickel up to 5% in bare electrodes on nitrogen pick up is not clearly indicated by available data. Depositing two bare electrodes, Schuster[8] secured the results shown in Table 9. Bare nickel-plated electrodes deposited metal containing 0.31 to 0.79 Ni which, upon

Table 9—Nitrogen Pick Up as a Function of Nickel Content of Electrode. Schuster[8]

Composition of Electrode				Composition of Deposit				
C	Si	Mn	Ni	C	Mn	Ni	N_2	
0.09	0.18	0.42	2.20	0.07	0.20	2.10	0.156	Electrode negative
0.09	0.18	0.42	2.20	..	..	1.32	0.089	Electrode positive
0.23	..	0.50	5.13	..	..	..	0.056	Electrode negative no needles

microscopic examination, was found to be plentifully sprinkled with nitride needles and braunite, despite the fact that nickel suppresses the formation of nitride needles. When the weld made from the 5.13% Ni electrode was annealed in hydrogen 4 hr. at 800° C. followed by a few minutes at 900° C., numerous needles appeared which were not visible in the as-welded deposit. These needles were attributed to the reduction of so-called nitrogenous carbides.

In bare electrodes Kleinefenn[38] was unable to detect any effect due to nickel, but in coated electrodes nickel (or vanadium) was instrumental in reducing the nitrogen pick up, as shown in Table 10. Haardt[37] also found nickel ineffective in reducing nitrogen pick up by a bare electrode. A two-layer deposit at 155 amps. contained

Table 10.—Nitrogen Pick Up as a Function of Nickel Content of Welding Rod. Kleinefenn[38]

Specimen	C	Si	Mn	P	S	Ni	Other Elements	N_2	O_2	Specimen
	0.02	0.01	0.04	0.010	0.03	..	..	....	....	Filler rod 1
1	0.02	0.01	0.03	0.012	0.021	..	..	0.0137	0.0507	Oxyacetylene
2	0.01	0.01	0.00	0.010	0.031	..	..	0.1620	0.2370	Bare electrode, d.c.
3	0.04	0.03	0.67	0.035	0.039	..	..	0.0213	0.1140	Coated electrode, d.c.
4	0.04	0.02	0.62	0.033	0.038	..	..	0.0503	0.1240	Coated electrode, a.c.
	0.10	0.02	0.35	0.020	0.02	..	..	....	....	Filler rod 6
5	0.05	0.01	0.28	0.024	0.018	..	..	0.0209	0.0507	Oxyacetylene
	0.08	trace	0.47	0.013	0.03	..	..	....	....	Filler rod 2
6	0.04	0.01	0.12	0.019	0.019	..	..	0.1230	0.2100	Bare electrode, d.c.
7	0.11	0.03	0.72	0.036	0.040	..	..	0.0197	0.1020	Coated electrode, d.c.
8	0.10	0.03	0.67	0.036	0.041	..	..	0.0286	0.1170	Coated electrode, a.c.
	0.12	0.01	0.25	0.012	0.02	2.00	0.2 Mo	....	....	Filler rod 4
9	0.04	0.01	0.16	0.016	0.018	2.00	0.09 Mo	0.0334	0.0591	Oxyacetylene
	0.15	0.03	0.35	0.012	0.02	3.50	0.75 Cr	....	....	Filler rod 5
10	0.09	0.03	0.24	0.014	0.017	3.10	0.68	0.0053	0.0239	Oxyacetylene
	0.05	0.02	0.46	0.010	0.02	2.30	..	....	....	filler rod 3
11	0.04	0.01	0.12	0.017	0.028	1.98	..	0.1660	0.1780	Bare electrode, d.c.
12	0.21	0.01	1.43	0.012	0.021	1.97	0.22 V	0.0054	0.0447	Coated electrode, d.c.
13	0.18	0.01	1.19	0.012	0.027	1.95	0.22 V	0.0174	0.0468	Coated electrode, a.c.

The last two electrodes had vanadium in the coating. The oxyacetylene rods were 0.24 inch diameter, and the torch delivered 78 to 84 cu. ft./hr. oxygen plus acetylene at a ratio of 1 to 1.05. The electrodes were 0.16 inch diameter, 100 to 140 amps. bare, 140 to 160 amps. coated. The base metal contained 0.09 C, 0.65 Mn, 2.5 Ni for the nickel steel welds. The gas analyses are averages of 2 to 6 determinations, which checked closely, containing 0.07 C, 0.4 Mn on a plate containing 0.1 C, 0.2 Si, 0.4 Mn, 3.5 Ni.

0.15% nitrogen. These results are confirmed by Shun-ichi Satoh[39] who found 0.119% nitrogen in a deposit from a bare iron electrode, and 0.138% nitrogen in a deposit from a nickel-plated iron rod. Nickel was also found to suppress needle formation.

In oxyacetylene welding, Kleinefenn's analyses are not sufficiently numerous to establish an effect due to nickel. Hoffmann,[30] however, found that nickel is a valuable addition for preventing nitrogen pick up. His analyses, Table 11, are almost unbelievably high for gas welds in plain carbon steel, and since important details of experimental procedures are not disclosed, his results must not be given too much weight. Hoffmann makes a similar claim for the beneficial effect of nickel on nitrogen pick up in metal arc welding but his work is too sketchily described to be convincing. According to Schmitt,[40] there

Table 11—Nitrogen Pick Up as a Function of Nickel Content of Filler Rod. Hoffmann[30]

C	Si	Mn	Ni	P	S	O_2	N_2	Specimen
0.10	0.06	0.32	..	0.015	0.025	0.080	0.028	Filler rod
0.05	0.03	0.03	..	0.015	0.024	0.120	0.082	Oxyacetylene weld
0.10	0.15	0.40	1.75	0.010	0.021	0.040	0.005	Filler rod
0.08	0.08	0.32	1.60	0.010	0.022	0.045	0.012	Oxyacetylene weld

was a 29% decrease in nitrogen pick up in bare electrode welds when the electrode was plated with nickel to the extent of 3% by weight. The nickel coating was said to make access of air to the arc more difficult.

Chromium

On the basis of analyses of deposits from bare electrodes in two high-chromium steels, 13.7 Cr, and 0.10 C, 28.9 Cr, which showed 0.30% nitrogen in the former deposit, 0.52% nitrogen (with 28.6% Cr in the latter deposit, Portevin and Séférian[26] concluded that chromium in bare electrodes favors nitrogen pick up. Fusion under the blowpipe of the steel containing 28.9 Cr produced a metal containing 0.127% nitrogen. New micro-constituents were observed in these high-chromium-nitrogen deposits but no details were disclosed. Nitrogen pick up refined the grain structure of the welds. Schuster[5] likewise found 0.26% nitrogen in a deposit made by a negative bare electrode containing 0.08 C, 0.47 Ni, 15.8 Cr. Although the deposit contained so-called nitrogenous carbides and grain boundary films of braunite, no needles were present. Other tests, however, convinced Schuster that chromium is a less powerful inhibitor of needles than manganese. Sonderegger[41] is of the opinion that chromium is one of very few elements that *decrease* nitrogen pick up.

Other Elements

Aluminum in bare electrodes increases nitrogen pick up, as shown by Portevin and Séférian[26] in Table 12. The compound AlN was said to be present. (The compound AlN is stable up to 1500° C., according to Eilender and Meyer, 1930.)

Table 12—Nitrogen Pick Up as a Function of Aluminum Content of Electrode. Portevin and Séférian[26]

Al in bare iron electrode, %	0	5	11.8
Nitrogen in weld deposit, %	0.16	0.18	0.22

Without supplying details of their procedure, Portevin and Séférian[42] prepared bare electrodes from electric furnace melts of Swedish iron fused with a number of ferro-alloys. The arc-deposited weld-metal was analyzed for nitrogen, the results of which are shown in Fig. 1. Molybdenum most actively increases nitrogen pick up, then zirconium, chromium, aluminum and vanadium, in order. Uranium, silicon, manganese, titanium and carbon decrease nitrogen pick up, carbon having the greatest effect, uranium the least. The following compounds were observed: TiN (titanium nitride), ZrN, VN, U_5N_2 and possibly AlN. In view of Kleinefenn's[28] discovery that a coating containing vanadium decreased nitrogen pick up, the statement that vanadium increases pick up cannot be accepted without reservation. Copper appears to have no effect on nitrogen pick up, so far as Haardt's[37] experiments show. A bare plain-carbon steel electrode deposited on copper steel (0.07 C, 0.82 Mn, 1.38 Cu) contained 0.15 N_2 and 0.6 Cu (one layer, 110 amps.) or 0.14 N_2 and 0.15 Cu (two layers, 155 amps.). Diegel[43] found that oxy-acetylene welds made from an iron wire nitrided in ammonia, so as to contain an average of 0.064% nitrogen, were of good quality (0.04 C, 0.02 Mn) and showed no signs of nitride brittleness.

In concluding the review on the influence of alloying elements on nitrogen pick up, it is well to keep in mind that significant changes in nitrogen content may be found, Table 13, in apparently identical welds. Unequivocal effects appear to be demonstrated only for carbon and silicon as decreasing nitrogen pick up and for chromium as increasing it. In contrast with the dearth of information on the much more important influence of, for example, coatings on nitrogen pick up, the large amount of investigation on alloying elements has scarcely justified itself.

Table 13—Nitrogen Pick Up in Bare Electrode Deposits. Lohmann and Schulz[6]

C	Si	Mn	Cu	Cr	N_2	Specimen
0.13	0.35	0.68	0.78	0.38	...	Bare electrode
0.03	0.08	0.22	0.79	0.25	0.123	Butt weld in plain carbon steel (0.08 C, 0.45 Mn)
0.04	0.12	0.42	0.79	0.36	0.113	Butt weld in plain carbon steel (0.26 C, 0.2 Si, 0.6 Mn)
0.04	0.10	0.50	0.81	0.30	0.103	Butt weld in alloy steel (0.18 C, 0.4 Si, 1.0 Mn, 0.75 Cu, 0.4 Cr)
0.04	0.09	0.43	0.81	0.36	0.109	Butt weld in alloy steel (0.11 C, 0.6 Si, 1.0 Mn, 0.70 Cu, 0.35 Cr)

2. Welding Atmosphere

The pick up of nitrogen by welds made in air has been summarized in Table 1. A number of investigators have studied the effect on nitrogen pick up of welding in atmospheres other than air, but apart from atmospheres created by coatings. In 1918 J. C. Lincoln[44] found that welds made by a modified carbon arc process (no details) in an atmosphere of 90% nitrogen, 10% CO_2 contained fewer nitride needles than welds made by the same process in air. The Westinghouse Company[45] also reported that nitrogen pick up in arc welds is less in an atmosphere of 98% nitrogen (no details) than in air. These observations probably strengthened the early and mistaken belief that needles in welds were not nitrogenous. For example, Goodger[31] stated that welds made in an atmosphere of oxygen (no details) showed needles in the microstructure. However, Ruder[46] proved that welds made in purified hydrogen or carbon dioxide contained no nitrides and Schuster[47] demonstrated that deposits on Armco iron made with mild steel, Swedish iron and coated electrodes in purified oxygen or carbon dioxide contained no needles, whereas similar welds made in nitrogen were full of needles, although no chemical analyses for nitrogen were made.

Experiments that have been made up to the present on the pick up of nitrogen by welds made in controlled atmospheres leave much to be desired. Willey[48] arced Armco iron electrodes (8 s.w.g., 38 to 40 volts arc, 5 amps.) In a glass bulb in a current of chemically purified and dried nitrogen (no analysis of nitrogen) at a pressure of $4^1/_2$ to 9 inches of mercury, which appears to have given opportunity for infiltration of air at a flexible joint. In three tests the black deposit on the walls of the bulb contained 0.24 to 0.27% nitrogen. The tips of the electrodes contained 0.05% nitrogen but the portions of the electrodes that remained cool during test contained none. The product obtained in tests with air in the bulb contained 0.10 to 0.12% nitrogen mixed with ferric oxide. Nitrous gases were formed (no details).

Similar experiments were made by Weber,[49] but the gas in his experiments was contained in a glass bell jar over water. Air could not be used because the water seal was broken by the rapid consumption of oxygen, but tests in nitrogen, which contained 0.6% oxygen before entry into the bell jar, resulted in a soot containing 90.3% Fe. On inadequate grounds Weber believed the deposit to be Fe_8N_2, a compound whose existence is very

unlikely. Weber's gas undoubtedly contained water vapor.

Miller's[35] experiments were made with 5/32-inch bare electrodes (0.13 to 0.18 C) in a pipe shield permitting some (unspecified) contamination by oxygen and are of considerable practical importance. His results with mixtures of hydrogen and nitrogen are shown in Table 14. Miller believed his results confirmed the hypothesis that pick up is a function of the partial pressure of the gas.

Table 14—Nitrogen Pick Up in Nitrogen-Hydrogen Atmospheres. Miller[35]

Atmosphere (volume %)	% Nitrogen in Deposit
Pure hydrogen	0.0255
75% H_2—25% N_2	0.0500
25% H_2—75% N_2	0.0717
Pure nitrogen	0.143
Air	0.107

If oxygen contamination is neglected, it appears that 25 vol. % O_2 permits considerably more nitrogen pick up than 25 vol. % H_2, although the mol. % of the latter gas is much higher.

The extensive tests on welding atmospheres made by Portevin and Séférian[26] also involved a water seal the contaminating effect of which was not evaluated. An automatic arc welder and bare electrodes were used and the gas pressure was maintained at 0.12 inch of water above atmospheric when the arc was not burning. The arc was struck after the gas had passed for 1 hr., the flow continuing while the arc burned at 150–180 amps. 16–22 volts. The arc increased the pressure to 0.39 to 0.78 inch of water. The results are given in Table 15. In the absence of details of gas purity it is difficult to interpret the results.

Table 15—Nitrogen Pick Up in Different Atmospheres. Portevin and Séférian[26]

Atmosphere	% Nitrogen in Deposit	Microstructure
Short arc (0.08 inch) in air	0.15–0.16	Fe_4N + braunite
Short arc in nitrogen	0.16–0.17	Fe_4N + braunite
Short arc in ammonia	0.12–0.13	Fe_4N in ferrite
Short arc in hydrogen	0.010–0.015	Ferrite

Portevin and Séférian also fused Armco iron rods 0.16 inch diameter in an oxyacetylene flame surrounded by a sheath of different gases, Table 16. Evidently, ammonia is much more effective than nitrogen in increasing nitrogen pick up. The butt weld was made between Armco iron plates 0.32 inch thick. At a distance of 0.39 inch from the axis of the weld the plates contained 0.04–0.05% nitrogen. An oxyammonia flame was too weak to melt an Armco rod completely but the melted surface of the rod appeared to contain nitrogen. The deposit from an Armco iron rod[50] in an atomic nitrogen flame (arc between two tungsten electrodes in nitrogen at 100 volts, 40–60 amps.) contained 0.25–0.40% nitrogen.

Table 16—Nitrogen Pick Up in Oxyacetylene Welds Made in Different Gases. Portevin and Séférian[26]

Sheathing Gas	% Nitrogen in Deposit
Air	0.02
Hydrogen	0.01–0.015
Nitrogen	0.03
Ammonia	0.08–0.09 in beads
Ammonia	0.05–0.06 in butt weld

Contrary to Weber's experience, Holland[51] found difficulty in arc welding with bare mild steel electrodes in nitrogen, copious gray fumes being evolved. The arc voltage was 27 in nitrogen, 25 to 23 in oxygen and air. The volume of slag was about normal in nitrogen when covered electrodes were deposited but the slags had a glassy appearance, perhaps because oxide depletion had occurred. The gas collected from welds (no details) made in air contained up to 8% N_2, 50–60% H_2, 33–39% CO, 2–6% CO_2, up to 5% CH_4.

Automatic metal arc welds in mild steel made under a stream of hydrogen with bare electrodes contained 0.03 C, 0.081 N_2, according to Wallmann and Pomp.[52]

Streb[53] stated that the nitrogen present as an impurity in oxygen used for welding seems to prevent excessive pick up of carbon by the steel weld-metal when a slightly reducing flame is used.

3. Coatings

Table 1 shows that coatings applied to the electrode may reduce the nitrogen content to 0.02% or less. Apparently all industrial coatings reduce nitrogen pick up. Hoyt found 0.010% nitrogen in a deposit made with cellulose covered electrode and Hiemke found less than 0.035% nitrogen in a deposit made with an inorganic covered electrode. However Doan and Schulte[34] using a pure iron electrode with cellulose covering found 0.017% nitrogen in a deposit made in argon and 0.098% nitrogen in a deposit made in air. Hackert and Zeyen's results, Table 1, shows that cored electrodes may deposit metal containing 0.10% nitrogen, whereas covered electrodes with the slag-forming or shielding constituents (no details) on the outside deposit metal containing only 0.010–0.036% nitrogen. Nothing definite appears to be known about the relative effectiveness of the different constituents of coatings in reducing nitrogen pick up, although Lohmann[54] believes that the coating should not contain iron oxide if low nitrogen pick up is desired.

As the thickness of the coating is increased the decrease in nitrogen pick up at first is rapid but increasing the thickness beyond a critical thickness appears to have little effect, as shown by Portevin and Séférian[26] in Table 17. Armco iron rods, 0.16 inch thick, were coated with a mixture containing 47% Fe_2O_3, 41% SiO_2, 8% Al_2O_3, 3% Na_2O, 1% loss in arc. An automatic welder was used, 140–160 amps., 18–22 volts, 0.08-inch arc length. The carbon content of all samples did not exceed 0.02%. Hoffmann[55] reported somewhat similar results to Portevin and Séférian but too little is know of his experimental procedure. Using an electrode containing 0.11–0.15 C, 1.2–1.5 Mn, <0.08 Si, <0.04 P, <0.04 S coated with 27.0% ilmenite, 13.5% pyrolusite, 27.0% feldspar, 15.0% ferromanganese (70% Mn), 10% sawdust, 12.5% waterglass (weld-metal contained 0.1 C, 0.5 Mn), Diatlov[56] found it impossible to drive the nitrogen pick up below 0.02% by increasing the

Table 17—Nitrogen Pick Up as a Function of Thickness of Coating. Portevin and Séférian[26]

Radial Thickness of Coating, Inch	S/S_1	% Nitrogen in Deposit	Microstructure
0.000	0	0.160	Fe_4N + braunite
0.012	0.0225	0.130	Fe_4N in ferrite
0.030	0.140	0.045	Ferrite
0.045	0.330	0.040	Ferrite
0.098	1.560	0.030	Ferrite

S/S_1 = ratio of area of covering, S to area of electrode core S_1.

thickness of the coating. A slight lime wash coating on a bare electrode containing 0.37 C, 1.0 Mn increased the nitrogen pick up from 0.087% (bare) to 0.096% (lime wash) at 18 volts, 150 amps., according to Miller.[35] Paterson and Blair[16] also found that a thin coating of lime had no effect on the nitrogen pick up with mild steel electrodes. Sekiguchi[69] found that nitrogen pick up increases with increase in potassium ferrocyanide in the coating.

4. Arc Length and Voltage

An increase in length of arc, other conditions remaining as nearly constant as possible, increases nitrogen pick up slightly. Depositing bare electrodes (0.09 C, trace Si, 0.47 Mn, 0.019 S, 0.009 P) 0.16 inch diameter by means of an automatic welder on mild steel $^1/_2$ inch thick at the rate of 36 ft./hr., Leitner[57] found that the nitrogen content of the deposit was:

Arc length, inch	0.12	0.28	0.51
Nitrogen in deposit, %	0.092	0.101	0.123

Under similar conditions (0.16 inch bare Armco iron electrodes, automatic welder), Portevin and Séférian[26] found:

Arc length, inch	0.08	0.16–0.20	0.24–0.32
Nitrogen in deposit, %	0.15–0.16	0.17–0.18	0.19–0.20

Petrov and Plutschek[58] state that nitrogen pick up is directly proportional to arc length. The qualitative fact that long ares favor nitrogen pick up has been a commonplace for a long time. Miller[35] found that an increase in arc voltage slightly increased the nitrogen pick up, Table 19. Rather more pronounced results in the same direction were secured by Hensel and Larsen,[24] Table 18 (no details). Portevin and Séférian[50] and others make the qualitative statement that nitrogen pick up is decreased as voltage is decreased.

Table 18—Nitrogen Pick Up as a Function of Arc Voltage. Hensel and Larsen[24]

Arc Voltage	Weight % Nitrogen in Deposit
13	0.114
18	0.121
24	0.126
31	0.135

5. Current and Diameter of Electrode

According to Miller,[35] the welding current does not have much effect on nitrogen pick up, Table 19. Rawdon[59] also found that increase in current density from 4000 to 12,000 amps./sq. in. had little effect on nitrogen pick up with bare electrodes (0.09 to 0.16% nitrogen in the deposits independent of current density). Using bare electrodes 0.16 inch diameter, 110–175 amps. Haardt[37] found that changes in current had no effect on nitrogen pick up. However, Leitner[57] stated that as the current is decreased nitrogen pick up is increased, and Boitzov and Sorokin[60] came to the same conclusion as a result of tests on bare electrodes (0.22–0.25 C) up to 450 amps. Weld pads deposited by Hensel and Larsen,[61] using bare electrodes containing 0.02 C, contained 0.162% nitrogen at 150 amps. and 0.145% nitrogen at 250 amps.

Table 19—Nitrogen Pick Up as a Function of Current and Voltage. Miller[35]

	125			150			190–200			Amperes
	12	18	24	12	18	24	12	18	24	Arc-volts
A	0.115	0.119	0.122	0.115	0.113	0.124	0.117	0.112	0.115	% nitrogen
B	0.085	0.095	0.096	0.089	0.087	0.078	0.084	0.084	0.085	% nitrogen

Electrode A was $^3/_{16}$ inch diameter, 0.15 C, 0.5 Mn
Electrode B was $^5/_{32}$ inch diameter, 0.37 C, 1.0 Mn

A decrease in diameter of electrode leads to an increase in nitrogen pick up, as Losana's[33] tests clearly demonstrated, Tables 4, 7 and 20. Electrode D was coated with a mixture of carbon and ferromanganese, 25% of the weight of the core rod. The welding was done by an automatic welder.

Table 20—Nitrogen Pick Up as a Function of Diameter of Electrode. Losana[33]

Diameter of Electrode, Inch	Electrode A Nitrogen %	Electrode A Oxygen %	Electrode B Nitrogen %	Electrode B Oxygen %	Electrode C Nitrogen %	Electrode C Oxygen %	Electrode D Nitrogen %	Electrode D Oxygen %
0.04	0.264	0.953	0.218	0.720	0.190	0.748	....	....
0.08	0.188	0.805	0.180	0.550	0.130	0.522	0.102	0.190
0.16	0.150	0.512	0.130	0.302	0.090	0.321	0.032	0.150
0.24	0.120	0.293	0.105	0.105	0.075	0.203	0.014	0.121

Electrode	C	Mn	Si		
A	0.08	0.32	0.06	bare	d.c.
B	0.09	0.73	0.18	bare	d.c.
C	0.38	0.46	0.21	bare	d.c.
D	0.08	0.32	0.06	coated	a.c.

Less pronounced results were found by Miller,[35] Table 21, who used an electrode containing 0.13–0.18 C, 0.40–0.60 Mn, 0.06 Si max., at 17 volts, 150 amps. A nitrogen content of only 0.088% was found in a deposit of the $^1/_4$-inch electrode at 225 amps. Leitner[57] also stated that small electrodes tend to favor nitrogen pick up.

Table 21—Nitrogen Pick Up as a Function of Diameter of Electrode. Miller[35]

Electrode diameter, inch	$^3/_{32}$	$^1/_8$	$^5/_{32}$	$^3/_{16}$	$^1/_4$
Nitrogen in deposit, %	0.144	0.123	0.117	0.112	0.114

6. Polarity

The polarity of the electrode has little effect on nitrogen pick up by the weld-metal, as Miller[35] showed, Table 22, using a hard drawn bare electrode $^5/_{32}$ inch diameter (0.37 C, 1.0 Mn, 125 amps., 20 volts). However, the tips remaining on the electrode after the arc was broken, as well as buttons of metal flipped from the electrode onto cold metal contained much more nitrogen with straight polarity than with reversed. In passing, it may be mentioned that Willey[48] found 0.05% nitrogen in the tips of bare iron electrodes that had been arced together in air. Apparently, the tips of both anode and cathode electrodes contained the same amount of nitrogen.

Table 22—Nitrogen Pick Up as a Function of Polarity. Miller[35]

	% Carbon Electrode Negative		% Nitrogen Electrode Positive	
	C	N	C	N
Tips	0.105	0.092	0.105	0.053
Buttons	0.115	0.110	0.115	0.067
Weld-metal	0.125	0.090	0.06	0.098

7. Speed of Welding

An increase in speed of welding, according to Leitner,[57] Table 23, increases the nitrogen pick up. An automatic welder was used to deposit bare electrodes (0.09 C, trace Si, 0.47 Mn, 0.019 S, 0.009 P, 0.20 inch diameter, 200–220 amps.) on a mild steel plate $^1/_2$ inch thick. Nitride needles were observed in the slow beads but not in the rapid beads (60 ft./hr.). Hoffmann[55] pointed out that the number of globules per second increased from 30 to 75 in the range of welding speeds investigated by Leitner. On the other hand, Boitzov and Sorokin[60] found that nitrogen pick up decreases as welding speed increases, but the increase in speed was attained by increasing the current. The effect of the second layer, in Leitner's results should be noted. No explanation was offered.

Table 23—Nitrogen Pick Up as a Function of Speed of Welding. Leitner[57]

Speed of welding, ft./hr.	20	40	60
Nitrogen in single bead, %	0.132	0.147	0.159
Nitrogen in double bead, %	0.143	0.171	0.175

8. Cold Work

Both Miller[35] and Kessner and Specht[62] found that the nitrogen pick up in deposits made with bare hard drawn electrodes was the same as with annealed electrodes.

9. Type of Current

Coated electrodes deposited with alternating current appear to pick up more nitrogen than with direct current, as shown by Kleinefenn,[58] Table 10. Zeyen's[63] results, Table 1, also show slightly higher nitrogen pick up with covered electrodes using a.c. than d.c. Kleinefenn believed that the a.c. arc was more "activating."

10. Magnetic Fields

Longitudinal magnetic fields, especially d.c. fields, slightly increase the nitrogen pick up, according to Hensel and Maddox,[64] Table 24. Dust-coated electrodes $^3/_{16}$ inch diameter, 0.10% C, were deposited on low carbon steel plates. The deposit contained 0.02 C, 0.10 Mn, 0.01 Si, the recovery of these elements being unaffected by the field.

Table 24—Nitrogen Pick Up as a Function of Magnetic Fields. Hensel and Maddox[64]

Ampere Turns	Nitrogen in Deposit, % A.C. Field	D.C. Field
0	0.120	0.120
2400	0.129	0.151
4000	0.134	0.149

ORIGIN OF NITROGEN PICK UP

A study of the factors influencing nitrogen pick up makes it clear that the vital factors are the form and volume of the nitrogen presented to the electrode and weld-metal. Iron at 1600° C. is saturated with nitrogen at 1 atmosphere when the nitrogen content is 0.04%. The solubility increases as the temperature is raised (no data are available above 1600° C., but Houston[1] thought it quite likely that the nitrogen solubility increased greatly with temperature), so it is within the realm of possibility that the large nitrogen pick up in arc welds compared with other types of welds may be simply a reflection of the higher temperatures attained locally by the weld-metal in the arc processes. The fact that nitrides of iron are unstable above about 600° C. supports the belief that nitrogen pick up in molten weld metal is governed by temperature-solubility relationships, which depend on the partial pressure of the nitrogen above the weld-metal. The fact that the nitrogen remains in the weld metal during cooling to room temperature may be explained by the rapid rate of cooling of welds and by the formation of stable iron nitrides below about 600° C. Hodge[9] stated that bare electrode weld metal is supersaturated with nitrogen because equilibrium conditions are not established.

There seems to be no analogy between steel refining and welding on the basis of nitrogen pick up. Bessemer steel generally contains 0.01–0.3% nitrogen, arc furnace steel up to 0.016%, and open-hearth steel up to 0.008%. However, in all cases the rate of solidification of the steel in the ingot molds is much slower than in welds. Consequently, ample opportunity is afforded for diffusion of the nitrogen from the steel. Furthermore, in the manufacture of arc furnace steel, the arc is switched off perhaps a half hour or so before the steel is poured and frozen. Unfortunately, samples taken from under the arc in arc furnaces during operation do not appear to have been analyzed for nitrogen.

The function of coatings in reducing nitrogen pick up may be to reduce the partial pressure of nitrogen in contact with the weld-metal. The slag covering protects the molten metal from contact with air, but bare metal generally is supposed to be exposed to form the cathode and anode spots. The coating may contain constituents that evolve gases at the temperatures in and near the arc. The gases dilute the air around the arc, thereby reducing the partial pressure of nitrogen. The coating constituents also may combine with nitrogen to form compounds (gas), such as CN, that may have lower solubility in molten iron than nitrogen. The coating may also change the arc temperature and the maximum temperature attained by deposited metal.

Returning to the preceding review of factors influencing nitrogen pick up, we see that weld-metal picks up nitrogen from a nitrogen atmosphere, although the experimental technique that has been applied to the problem has been somewhat crude. As the nitrogen is diluted by other gases the nitrogen pick up generally decreases. However, Portevin and Séférian's results, Table 16, showed that a sheath of ammonia was much more effective in increasing nitrogen pick up than a sheath of nitrogen. The temperature of the flame and weld metal was not reported. The result may be interpreted, perhaps, on the basis of ionized nitrogen. Iron may be converted to nitride at temperatures as low as 450° C. by ammonia. It is believed that the atomic nitrogen liberated upon decomposition of the ammonia on the surface of the iron, which acts catalytically, is the effective agent in forming the nitride, and, indeed, in permitting the nitrogen atom to penetrate the surface of the iron to form the solid solution preliminary to nitride formation.

Arguing on the existence of ionized or atomic nitrogen in the arc, a number of investigators attribute nitrogen pick up in the arc to active nitrogen. Paterson and Blair[16] and Willey[48] believed that active nitrogen had something to do with nitrogen pick up. Paterson and

Blair quote Strutt as authority for the statement that active nitrogen is formed in an arc in nitrogen and assume that active nitrogen will combine in some way with molten iron. They had no evidence for the existence of active nitrogen in a welding arc and there is no evidence that active nitrogen behaves in an unusual way with molten iron. As a matter of fact, Willey[48] found that nitrogen from a 7000 volt Siemens ozonizer had no effect on iron at 500° C. The nitrogen was called "activated" by Willey, but there is no reason to believe that the activated gas was active nitrogen, which has an exceedingly short life outside its source. Schuster[29] believed that ionization of nitrogen in the arc was responsible for the high nitrogen content of arc-weld-metal made with bare electrodes. There is no evidence that ionized nitrogen has unusual effects on molten iron. Unless there were unusual effects, we would not expect any ionized gas to be picked up in unusually large quantities by arc-weld-metal. It must be admitted that we are quite in the dark concerning the solubility of ionized gases in liquid metals and the only evidence for the possible effect of ionized gases on molten metals appears to be provided by the arc welding experiments themselves. Ruder[46] evolved the hypothesis that nitrogen pick up is related to the reaction of iron vapor with atomic nitrogen in the arc stream, but he offered no experimental evidence in support.

Several, although not all, investigators have found that nitrogen pick up is greater in air than in nitrogen itself. The Westinghouse Company[65] believed the increased nitrogen pick up in air was due to a nitrogen-oxygen compound which served in some unexplained way to supersaturate the molten iron with nitrogen. A Russian investigator[66] believed that oxygen may be necessary for the pick up of nitrogen by iron in the same way that oxygen facilitates the nitriding of iron in ammonia at 500° C. Jevons and Wheeler[67] observed a close association of nitride needles with oxide inclusions in welds, but many other investigators of the microstructure of bare electrode deposits have not observed any relation between needles and oxide inclusions. However, it is true that in all cases, bare electrode deposits in air contain abnormally large quantities of oxides as well as nitrogen and that coatings generally decrease nitrogen and oxygen pick up simultaneously. Besides there is ample evidence that nitrous gas is formed in many types of fusion welding,[68] particularly arc welding. Willey[48] detected gaseous nitrogen compounds in the gas resulting from arcing iron electrodes in air. However, there is no information on the solubility of NO or similar compounds in iron.

Woshtchanov[66] considered it likely that an intermediate compound (NO perhaps) may account for nitrogen pick up. On the other hand, Bissell[70] believed that it was an envelope of iron oxide vapor around the arc which reduced the nitrogen pick up in short arcs ($^1/_8$ to $^3/_{16}$ inch). Paterson and Blair[16] on very weak evidence postulated two forms of nitrogen in bare electrode deposits. One form was related to the oxygen content of the deposit; the other was a solid solution of iron nitride. According to Shamovsky and Prokorov,[71] nitrogen is activated in the arc only in the presence of oxygen; hence nitrogen pick up in a nitrogen atmosphere decreases as the oxygen content is reduced. On this basis only activated nitrogen can be dissolved in molten iron, which is not in agreement with Chipman's results.

The effects of numerous factors on nitrogen pick up that were discovered by Miller[35] were believed by him to be consistent with the hypothesis that atomic nitrogen or NO is responsible for nitrogen pick up. For example, Miller points out that Steinmetz deduced on theoretical grounds that an increase in temperature decreases the concentration of NO in arcs in general. Assuming that an increase in current raises the arc temperature, it follows that an increase of welding current will decrease the nitrogen pick up if the pick up depends upon a reaction between nitric oxide and iron.

Miller believed that NO decomposed in the cooler parts of the arc to form active atomic nitrogen and oxygen both of which were presumed to react with iron with special vigor. He found it necessary to postulate that the solubility of nitrogen in weld-metal decreases with an increase in temperature at welding temperatures. Data now available indicate that the nitrogen solubility in molten iron increases slightly with increase in temperature, at least up to 1600° C. Nevertheless, Miller's results were conclusive that carbon is eliminated under the same conditions that nitrogen is picked up. It appeared plausible, therefore, to deduce that the active atomic oxygen liberated upon decomposition of NO in the arc combined with the carbon, the active atomic nitrogen entering the iron. Miller did not indicate in what way active atomic nitrogen could be expected to combine with molten iron, and once combined, in what way the compound could achieve stability. In contrast to Miller, Willey[48] believed that graphite as an electrode coating is effective in reducing nitrogen pick up, because carbon has a great affinity for oxygen and prevents the formation of a complex Fe-N-O compound (no details) which was thought to be stable at welding temperatures.

Although explanations of nitrogen pick up based on special forms of nitrogen or special compounds of iron, nitrogen and oxygen for which there is no direct evidence have obvious shortcomings, the available experimental evidence requires something more than the simple conception of partial pressure of nitrogen for its satisfactory explanation. Since iron oxide as a constituent in electrode coatings is said to increase nitrogen pick up, and since in air the weld-metal contains a good deal of oxygen, probably in part as iron oxide, as well as nitrogen, it may be that FeO increases the solubility of nitrogen in iron at welding temperatures.

All things considered, the origin of nitrogen pick up in iron weld metal seems to lie in the solubility of nitrogen in molten iron at welding temperatures. It is very unlikely that any iron-nitrogen compound alone or with oxygen is stable at welding temperatures. At any rate none has ever been observed. Consequently, the nitrogen is dissolved as nitrogen (1) while the molten metal is still on the electrode; (2) during passage to the bead of weld-metal; (3) while the metal is in the overheated molten state in the deposit. Whether the nitrogen is adsorbed as atoms, ions or molecules on the surface of the liquid iron prior to solution is not known, nor is it known whether the nitrogen dissolves as a nitrogen-oxygen compound when the welding is done in air. Available information suggests that the pick up is a complex function of the partial pressure of the nitrogen over the weld-metal, the maximum temperature of the weld-metal (near the boiling point for arc welds, not much above the melting point for gas welds), the size of the weld puddle, the rate of cooling and the presence of impurities in the weld-metal which may either increase the solubility of nitrogen in molten iron at welding temperatures or form stable compounds with nitrogen. The partial pressure of nitrogen can be controlled (decreased) by coatings or fluxes. No quantitative information suitable for detailed consideration is available on the effects of maximum temperature of weld-metal, size of puddle or rate of cooling. The larger the volume of the puddle with respect to the exposed surface the less opportunity

would there be for diffusion of nitrogen from the weld-metal during cooling. But the larger the puddle the slower is the rate of cooling in general, which would favor loss of nitrogen by diffusion. Considerable information is available on the effect of impurities in the iron on nitrogen pick up.

METALLOGRAPHY

Since the mechanical properties of welds containing nitrogen are determined to a large extent by the metallographic form of the nitrogen, the available metallographic information will be summarized first. In 1911, B. Strauss[72] found a needle-shaped constituent in arc welds containing 0.12% nitrogen. By comparison with iron nitrided in ammonia, Strauss deduced that the needles were iron nitride in both the weld and the nitrided iron. At about the same time Law[73] observed similar needles in arc welds but called them iron oxide (Fe_3O_4). His error was perpetuated by Alexander[74] in the face of evidence that the needles were iron nitride, Fe_4N. Rawdon[59] clearly showed that the needles are plates and that during the annealing of welds the plates grow and oxide globules grow, but there are no intermediate forms between the nitrides and the oxides.

A general review of the metallography of nitrogen in welds is given by Harris[75] who bases his discussion on Hodge's[76] well known research. Furnace-cooled from a high temperature (1000° C.), high-nitrogen weld-metal exhibits a microstructure consisting of nitride needles distributed uniformly through the ferrite with areas of iron-iron nitride eutectoid, known as braunite, distributed somewhat like pearlite through the steel. Pearlite, as Hoyt[21] showed, can be distinguished from braunite by means of a weak cupric etching reagent (Comstock solution), which attacks braunite more rapidly than pearlite. Upon being water quenched from increasingly higher temperatures there is partial solution of the nitride needles at 400° C., complete solution of the needles at 500° C., and complete solution of the braunite at 700° C., which, as Hodge pointed out, is consistent with the iron-nitrogen equilibrium diagram. The eutectoid in low-nitrogen weld-metal (covered electrode short arc) does not disappear upon being water quenched from 700° C., because it is the iron-carbon eutectoid, known as pearlite. Water-quenched from 700° C. the braunite in the high-nitrogen weld-metal is replaced by nitrogen martensite. Samples water-quenched from 900° C. consist entirely of nitrogen martensite. Nitride needles are not visible in high-nitrogen welds water-quenched from 600° C. and reheated to 200° C. for 1 hr., but are visible in specimens reheated to 300° C. for 1 hr. Longer reheating treatments (Hensel and Larsen[61] found needles in a weld-metal water-quenched from 600° C. and reheated 70 days at 200° C.) or higher temperatures favor agglomeration of the nitride into larger needles, depending on the nitrogen content. Hodge does not illustrate the structure of tempered nitrogen martensite, although Séférian[26] claims to have identified troosto-braunite, nor has any investigation of the "S curve" been made for high-nitrogen weld-metal. It should be noted that Hodge cautiously refers to the eutectoid constituent in high-nitrogen weld-metal as "probably a complex eutectoid similar to the iron-nitrogen eutectoid braunite."

The nitrogen content at which needles just appear in the microstructure of weld-metal appears to depend, among other things, on the rate of cooling from above 600° C. Schuster[77] showed that an electrode (0.12 C, 0.5 Mn) covered with iron oxide, silica, ferromanganese, and asbestos yielded a deposit containing 0.078 C, 0.020 N_2; yet needles were present when the deposit was cooled from 920° C. at comparatively slow rates. He was unable[8] to detect needles in a weld containing 0.04–0.10 C, 0.08–0.29 Mn, 0.018% nitrogen. Quadflieg[78] found that a weld-metal containing 0.09 C, 0.48 Mn, 0.18 Si, 0.043 P, 0.05 S, 0.032 N_2, 0.109 O_2 deposited by a covered electrode showed no needles in the as-welded condition. After annealing at 850° C. the nitride was present as globules, but in specimens air cooled from 850° C. needles were present. Hodge[76] was able to detect needles when the nitrogen content reached 0.035–0.040%. Rapid cooling preserved so-called nitrogen austenite in some of Schuster's[79] specimens, but the evidence for austenite was not definite. According to Schuster,[80] nitride needles precipitate on slip planes in the ferrite (in iron-nitrogen alloys not prepared by welding it has been shown by Mehl, Barrett and Jerabek (1934) that iron nitride plates precipitate on the 210 planes of ferrite) and when the precipitation occurs at 200° C., which it may during furnace cooling, there may be some effect on shrinkage stresses. However, Schuster's belief in a complex compound of iron, nitrogen and carbon in welds has not been definitely established.

Schuster[80] showed that in unrefined, dendritic, mild steel weld-metal, needles (no details) may cross the subboundaries of dendrites but usually show a slight change in direction thereat. Zeyen[63] showed that whereas untreated, high-nitrogen weld-metal may exhibit no needles, they appear after air cooling from 900° C. ($^1/_2$ hr. at temperature) or from 600° C. (2 hr. at temperature). Both Hoyt[21] and Hodge[76] point out the rapid diffusion of nitrogen from a high-nitrogen weld deposit into unfused base metal, which accounts for needles in the heat-affected zone of the base metal. Nitrogen has about the same rate of diffusion as carbon in ferrite.

The critical points of high-nitrogen weld-metal have been determined by Séférian,[26] Hensel and Larsen,[24] and Rawdon.[15] Séférian obtained four samples of different nitrogen content (0.05, 0.09, 0.14 and 0.20%) by depositing Armco iron electrodes, bare or with a neutral slag coating of different thicknesses presumably in air. Higher nitrogen contents were secured in two specimens (0.25 and 0.39%) by either depositing an Armco iron rod in the atomic nitrogen flame or by nitriding an iron tube 0.04-inch wall in ammonia. In the absence of oxygen and slag analyses it is difficult to be convinced that Séférian's arc-deposited metal represents anything like a pure iron-nitrogen alloy, but the presence of impurities lends practical importance to his determinations, Fig. 1, which appears to be that the solid solubility of iron nitride Fe_4N in ordinary weld-metal is considerably lower than indicated by the equilibrium diagram of pure iron-nitrogen alloys. By means of thermo-magnetic analysis Séférian found that the Curie point of Fe_4N in weld deposits is 480° C.

Séférian mentions that seven cycles of heating to, and cooling from, 950° C. resulted in the disappearance of braunite from the specimen containing 0.14% nitrogen. Presumably, the disappearance was caused by loss of nitrogen from the specimen to the air, the specimens being exposed to the air during the cyles of heating and cooling, Hensel and Larsen[24] found that annealing in hydrogen for 12 hr. at 1400° C. removed most of the nitrogen in a specimen originally containing 0.15% nitrogen, but Hodge[76] observed no change in nitrogen content in a bare electrode weld containing 0.13% nitrogen after heating 12 hr. at 600° C. or 8 hr. at 1000° C. in air.

In 1921 Rawdon[15] took cooling curves from 1000 to 150° C. on bare electrode weld-metal containing 0.03 C, 0.006 Si, 0.04 S, 0.13 N_2. The critical point A_3 was 830–840° C., the A_2 temperature being the same as pure iron. Hensel and Larsen,[24] using Chevenard and Scott dilatometers and weld-metal deposited by bare electrodes, found that the A_3 point was lowered by nitrogen in agreement with the Fry diagram, and that the A_2 point was not appreciably affected by nitrogen.

The effect of time at temperatures up to 600° C. on the magnetic properties and electric conductivity of iron-nitrogen alloys has been studied by a number of investigators, but only Hensel and Larsen[61] have made studies of these properties in high-nitrogen weld-metal. The specimens contained 0.02–0.03 C, trace to 0.27 Mn, 0.003–0.037 Si, 0.008–0.037 S, 0.005–0.027 P, 0.003–0.009 Al. The oxygen and nitrogen contents are shown in Table 25. Nessler's reagent is understood

Table 25—Nitrogen and Oxygen Contents of Weld-Metal Deposits. Hensel and Larsen[61]

Type of Weld	% Nitrogen in Deposit Vacuum Fusion	% Nitrogen in Deposit Nessler's Reagent	% Oxygen in Deposit Vacuum Fusion
Bare electrodes	0.093–0.171	0.128–0.147	0.183–0.785
Oxyacetylene	0.013	0.024	0.054
Atomic hydrogen	0.017	0.037	0.054

to yield the nitrogen present combined with iron and manganese, whereas the vacuum fusion method analyzes total nitrogen. Yet for some reason the Nessler's reagent returned higher nitrogen contents than the vacuum fusion method. The specimens were tested as-welded, after furnace cooling from 900° C. followed by heating for 24 hr. every 50 or 100° C. up to 600° C., and after water quenching from 600° C. followed by similar heat treatments.

The results showed that the maximum coercive force, which is considered usually to indicate a fine dispersion of precipitate particles, is obtained after water quenching from 600° C. followed by heating at 100–150° C., which is in agreement with results of other investigators on pure iron-nitrogen alloys. The coercive force was increased 150% by heating at 100–150° C. for 24 hr., remanence and permeability varying inversely with coercive force. Even after furnace cooling from 900° C. there was still enough nitrogen in solution to yield a noticeable peak in coercive force at 100–150° C. in the annealed specimens. Hensel and Larsen conclude that however slowly a weld is cooled, precipitation or aging effects may always be expected if the nitrogen content exceeds a few hundredths of a per cent. The specimens slowly cooled from 900° C. exhibited a second maximum in coercive force at 400–500° C. aging temperature which was not explained.

The electric conductivity of bare electrode weld-metal is decreased by water quenching from 600° C. but is increased during the course of time at room temperature. The oxyacetylene and atomic hydrogen welds showed practically no changes. After the bare electrode welds were furnace cooled from 900° C. in hydrogen, their conductivity first increased as the reheating temperature was increased to 100–200° C., then decreased to a minimum at 300 or 400° C., to rise to a pronounced maximum after reheating for 24 hr. at 500–600° C. The first maximum was considered to represent the precipitation of the remainder of the nitrogen held in solution even during furnace cooling. The minimum at 300–400° C. was taken to indicate re-solution of the nitrides. The maximum at 500–600° C. was not explained.

In their endeavor to show that microstructural changes occurred in weld-metal water-quenched from 600° C. and reheated at low temperatures corresponding to the changes in conductivity that were observed, Hensel and Larsen[61] were unable to detect any precipitate in the specimens held for 10 days at 25° C. In specimens aged 10 days at 100° C., however, they believed that they could detect the presence of a random profusion of medium-sized particles (500×) of sharp, irregular contour, which the investigators called nitrides but which did not appear to be browned by 2% nital. The particles have a dubious appearance and have not been reported by any other investigators. The familiar needles were observed in specimens held a long time at 200° C. or a short time at 300° C.

No X-ray study of precipitation of nitrides or other aging effects in high-nitrogen weld-metal appears to have been made. Burns[81] prepared synthetic weld-metal by nitriding Armco iron in ammonia. He concluded that, since the hardness increase in the nitrided iron on aging at 20° C. was not accompanied by a change in lattice parameter, nitride was not precipitated, and that hardening at 20° C. is of the "intra-solution" or "knot" type.

According to Ruder[82] it is the nitride in solid solution, not the needles, that causes brittleness in high-nitrogen welds after considerable time at room temperature. Owens,[83] on the other hand, found that nitride brittleness in welds is removed by water quenching from 540 to 980° C. to hold the nitrides in solution or by cooling slowly from 540° C. to obtain coarse needles which do not embrittle the weld. The question is discussed at length in the section on Mechanical Properties.

Applying the McQuaid-Ehn test to bare iron welds deposited in nitrogen containing 0.6% O_2, Weber[49] found that the deposits were abnormal, not to the extent that welds made in CO were abnormal but more abnormal than welds made in CO_2. He believed that dissolved nitrogen caused abnormality and strengthened his belief by demonstrating that whereas welds made in nitrogen-free helium were normal, welds made in helium containing 6% N_2 were abnormal. Weber did not analyze his welds for nitrogen and oxygen, and his method of purifying the helium by incandescent magnesium would have removed oxygen as well as nitrogen. In general, oxygen, rather than nitrogen, is considered to be a cause of abnormality in steel.

Cracks in arc welds in steel 0.06 and 0.47 inch thick containing 0.31 C, 0.91 Cr, 0.15 Mo, 0.6 Mn, 0.25 Si, 0.03 S, 0.03 P were attributed by Petrov and Plutschek[68] to nitrides. The cracks were prevented by keeping the nitrogen in solution by holding the weld a long time at 650° C. followed by air cooling. Fuchs[12] stated that penetration in arc welding does not vary with nitrogen content. According to Diatlov,[56] brittleness in arc welds is reduced by adding silicon and manganese (0.1 C, 0.5 Mn) to the weld. These elements are said to form stable nitrides. Molybdenum (0.62%) and nickel (2.46%) had no effect in reducing brittleness.

MECHANICAL PROPERTIES

There is practically no information on the mechanical properties of welds made in plates consisting of iron and nitrogen. Séférian[84] has made micro-mechanical tensile, shear and hardness tests on welded, dead soft open-hearth steel containing 0.03 C, 0.40 Mn, 0.00 Si, 0.034 P, 0.054 S, 0.018–0.020 N_2. In the form of cylinders 0.16-inch wall made by the vertical, two-

torch oxyacetylene method, the steel fractured in hydrostatic tests always at a distance of 1.6 inches from the weld, which corresponds to a maximum temperature of 320° C. attained during welding. The micro-mechanical tests showed that as a result of nitrogen precipitation, the steel had lower strength but higher elongation after slow cooling from 320° C. The low strength of the steel in the zone heated to 320° C. maximum during welding was considered to account for failure occurring in that zone.

Table 26—Mechanical Properties of Welds Containing Nitrogen and Oxygen. Kleinefenn[28]

Specimen	Treatment	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 1.2 In.	Reduction of Area, %	Brinell Hardness	Notch-Impact Value Mkg./Cm.²
1. Low-carbon rod No. 1, oxyacetylene welded	1	38,800	49,800	17.0	26.0	92	2.43
	2	36,300	47,200	20.5	30.3	80	2.52
	3	55,500	68,500	3.2	8.3	168	1.73
	4	63,500	73,500	1.6	6.0	181	1.07
	5	59,200	63,700	15.4	20.0	136	1.02
2. Low-carbon rod No. 1, bare, d.c. welded	1	27,200	32,000	1.7	2.0	120	0.52
	2	25,600	29,700	3.1	5.0	99	0.45
	3	36,400	44,800	1.0	0.0	175	0.39
	4	23,500	23,500	0.0	0.0	245	0.27
	6	41,600	44,800	1.5	2.0	143	0.48
3. Low-carbon rod No. 1, coated, d.c. welded	1	57,500	73,700	19.0	26.0	142	8.79
	2	46,100	65,000	24.3	34.0	124	3.72
	3	56,400	75,000	20.6	23.0	148	2.27
	4	73,000	103,000	14.0	18.1	156	1.80
	5	73,800	81,500	17.4	26.0	158	0.74
4. Low-carbon rod No. 1, coated, a.c. welded	1	58,000	75,000	18.4	24.0	148	7.73
	2	49,500	67,500	23.9	33.0	130	4.93
	3	68,000	86,000	16.6	26.0	168	1.98
	4	73,000	108,000	12.1	18.0	180	1.27
	5	76,000	84,500	17.2	25.0	167	0.67
5. Unalloyed rod No. 6, oxyacetylene welded	1	38,700	51,400	17.5	16.9	119	3.20
	2	34,100	53,800	21.8	19.4	100	4.10
	3	58,500	77,700	13.7	16.0	153	3.50
	4	58,300	70,000	6.2	6.6	184	1.73
	5	58,400	64,400	9.3	9.7	128	1.25
6. Unalloyed rod No. 2, bare, d.c. welded	1	42,000	46,300	5.2	4.4	140	1.02
	2	29,600	36,200	5.9	5.4	99	0.83
	3	50,700	56,900	2.4	2.8	172	0.56
	4	59,500	64,100	0.9	0.0	252	0.46
	6	42,500	48,000	4.7	3.6	146	0.66
7. Unalloyed rod No. 2, coated, d.c. welded	1	53,200	71,600	24.8	30.7	148	10.98
	2	46,200	68,700	26.1	40.0	130	5.11
	3	46,500	71,100	24.2	29.0	180	4.83
	4	55,800	82,400	21.8	27.0	200	3.34
	5	71,100	82,500	16.5	27.8	170	1.27
8. Unalloyed rod No. 2, coated, a.c. welded	1	58,900	71,800	23.6	29.8	163	8.65
	2	49,900	71,000	25.2	33.3	139	6.12
	3	59,100	76,700	22.1	30.0	191	4.13
	4	72,000	90,800	11.1	23.3	214	2.93
	5	80,700	88,500	13.3	28.0	177	0.81
9. Nickel steel rod No. 4 (2% Ni) oxyacetylene welded	1	60,800	68,500	21.7	20.0	141	3.20
	2	50,700	61,200	22.6	22.0	120	5.78
	3	73,000	87,500	11.0	12.0	179	4.49
	4	85,500	98,000	8.3	4.0	224	3.27
	5	70,900	74,500	10.4	9.8	154	3.03
10. Nickel steel rod No. 5 (3% Ni) oxyacetylene welded	1	62,200	82,500	15.7	16.0	187	3.89
	2	46,500	68,600	22.7	27.0	140	8.62
	3	48,800	72,200	20.1	28.0	150	8.58
	4	50,500	73,000	19.2	27.0	158	8.15
	6	69,500	74,500	18.5	12.4	152	5.05
11. Nickel steel rod No. 3 (2% Ni), bare, d.c. welded	1	42,500	48,100	4.3	6.7	151	3.67
	2	40,700	44,800	6.2	7.5	126	2.85
	3	45,800	55,000	2.2	2.9	175	2.29
	4	56,500	62,000	1.9	0.0	250	1.16
	6	55,600	59,500	1.5	1.2	168	1.31
12. Nickel steel rod No. 3 (2% Ni), coated, d.c. welded	1	96,000	107,000	11.4	23.5	204	6.49
	2	65,500	87,800	15.8	34.5	177	8.14
	3	70,300	87,500	15.1	28.0	189	7.56
	4	71,300	90,500	14.5	25.0	199	4.85
	5	95,500	101,000	11.6	20.5	202	5.30
13. Nickel steel rod No. 3 (2% Ni), coated, a.c. welded	1	97,500	110,000	11.7	19.3	214	3.96
	2	70,000	90,000	15.7	33.2	181	6.28
	3	74,700	92,300	12.4	25.7	206	6.04
	4	83,000	95,000	10.8	19.4	223	5.33
	5	104,000	105,000	8.8	17.8	214	4.43

Treatment 1 = as-welded.
Treatment 2 = held 1/4 hr. at 920° C., slowly cooled in furnace.
Treatment 3 = cooled from 600° C. in a stream of air; held 12 days at room temperature.
Treatment 4 = water-quenched from 600° C.; held 12 days at room temperature.
Treatment 5 = cold-worked 8%; tempered 1 hr. at 250° C.
Treatment 6 = stressed to 80% of tensile strength; load removed; tempered 1 hr. at 250° C.

The mechanical properties of weld-metal as a function of the nitrogen picked up during welding have been the subject of a number of investigations. Weld-metal being difficult to obtain in a state of purity, especially with respect to oxygen if the nitrogen content is high, many of the specimens used by investigators may be considered as high-oxygen, as well as high-nitrogen weld-metal. Consequently, there is some difficulty in deciding to which of the several impurities that may be present in a specimen of weld-metal may be attributed the characteristic properties of the metal. For example, Hoyt[21] concluded that the age hardening which he observed in his specimens was due to nitrogen in the case of deposits made by his bare and slag-coated electrodes, but to carbon in the deposit made by his cellulose covered electrode. Chatalbashyan[19] believed that several instances of excessive brittleness in carbon arc welds could be explained by nitrogen pick up. Wallmann and Pomp[52] showed that impact value, static bend ductility, and tensile reduction of area of automatic arc welds (0.03 C) in mild steel made in hydrogen are decreased 10 to 20% if the nitrogen content is 0.081% (oxygen content not stated) instead of less than 0.05%. The tensile strength was not affected even after treatment at 400 or 600° C. Fuchs[12] stated that tensile strength and elongation decrease as the nitrogen content of welds in mild steel is increased from 0.05 to 0.15% (no details). Hodge[85] stated in 1931 that the Bureau of Engineering (U. S. Navy) permitted not over 0.20% N_2 as iron nitride in boiler welds.

On the other hand, Doan and Schulte[34] believed that nitrogen is only partly responsible for aging brittleness in welds, and Leitner[20] showed that impact properties in high-nitrogen welds may be greatly affected by other factors than nitrogen, for example, some types of oxide. Reeve[5] concluded that, in general, FeO rather than nitrogen is the effective agent in reducing the ductility of welds. Shamovsky and Prokorov[71] showed that arc welds in mild steel made in oxygen had much lower notch-impact value than welds made in nitrogen or a vacuum. (For details, see the review of literature on The Effect of Oxygen on the Welding of Steel.)

The available quantitative information on the effect of nitrogen on mechanical properties of weld-metal is difficult to interpret because in all cases the welds either were known to contain significant quantities of other impurities, such as oxygen, which varied more or less in proportion with the nitrogen content, or else no analyses were made for impurities other than nitrogen, although their presence may be taken for granted.

The comprehensive investigation made by Kleinefenn[38] involved the welds described in Table 10. The mechanical properties of the welds are shown in Table 26. The tensile specimens were 0.24 inch diameter. The notch-impact specimen was 0.39 x 0.39 x 2.2 inches, machined from V butt welds in plate 0.47 inch thick. The notch was 0.08 inch diameter, 0.14 inch deep, and extended from root to face of weld.

The cold work followed by heating at 250° C. lowered the notch-impact value to 1.3 mkg./cm.^{2} or less in all cases, except the nickel steel welds. Fry etch figures appeared on all mechanically aged specimens, except the nickel steel welds. (Kleinefenn and others adopt the term aging for any treatment conducive to hardening or embrittlement of weld-metal. Aging may be a treatment consisting simply of holding the weld metal at room temperature for a period of time, or of reheating to a relatively low temperature, such as 250° C., or of straining followed by holding at temperature or at a relatively low temperature, such as 250° C.) The tensile ductility was seriously lowered by this treatment only in the bare electrode welds, including the bare nickel steel electrodes. Normalizing had little effect on notch-impact value except in the oxyacetylene welds, which were improved up to 200%. Water quenching was slightly more effective than air cooling from 600° C. in reducing the ductility and raising the strength of age-sensitive welds. However, the sensitivity to aging was not entirely dependent on nitrogen content. All specimens containing high nitrogen (2, 6 and 11) were sensitive to aging, but so also was specimen 1, which contained only 0.0137% nitrogen.

The precipitation hardening of the welds is shown in Table 27. Normalized specimens were heated 1/2 hr. at 600° C. They were then either C. quenched in water at 12° C.; B. cooled at the rate of 10° C. per sec. in a stream of air; A. cooled at the rate of about 1° C. per sec. All were aged 12 days at room temperature before being tested for hardness. Although Kleinefenn attributed the effects due to mechanical aging to oxygen, he believed that the precipitation hardening was related to the nitrogen content of the welds because the increases in hardness were approximately proportional to the nitrogen contents. Manganese appeared to decrease the precipitation hardening, which may be connected with the fact that manganese tends to suppress the formation of needles. In every case the precipitation hardening decreased as the cooling rate decreased, according to expectations.

Table 27—Precipitation Hardening of Weld-Metal. Kleinefenn[38]

Specimen	Brinell Hardness Normalized	Brinell Hardness Increase Over Normalized, % Treatment *A*	Treatment *B*	Treatment *C*
1	80	63	110	126
2	99	11	77	148
3	124	10	19	26
4	130	14	29	38
5	100	31	53	84
6	99	22	71	151
7	130	19	38	54
8	139	20	37	54
9	120	28	49	87
10	140	1	7	13
11	126	25	39	99
12	177	1	7	12
13	181	4	13	23

Kleinefenn showed that the hardness increased at first rapidly then more slowly as aging progressed at room temperature. In some welds, for example, specimen 5, the maximum hardness had not been reached even after 12 days at room temperature following a water quench from 600° C. In most welds, however, maximum hardness appeared to have been reached in 3 to 10 days.

The notch-impact value of the untreated and normalized welds at temperatures from −80 to +500° C. (no tests were made between 0 and −80° C.) was also determined by Kleinefenn.[86] Normalizing was done at 920° C. for 1/2 hr. At −80° C. all as-welded specimens had less than 1.7 mkg./cm.^{2}, and all normalized specimens had less than 2.0 mkg./cm.^{2} At 0° C. the welds made with coated electrode 2 had 4 to 8 mkg./cm.^{2} and the welds made with coated nickel steel electrode 3 had 3 to 4 mkg./cm.^{2}, but the remainder of the as-welded specimens lacked toughness. The normalized nickel steel welds made with coated electrodes had 5 to 10 mkg./cm.^{2} at 0° C., but normalizing did not improve the toughness of the plain-carbon steel welds. At 500° C. there was not much difference among the

welds, the maximum impact value occurring at 200° C. in most of the specimens. Kleinefenn frankly admitted that he was quite unable to explain the low-temperature notch-impact behavior of his welds. In common with other investigators Kleinefenn observed that untreated welds contained no needles whereas normalized welds exhibited needles if sufficient nitrogen was present. However, none of the nickel steel welds contained needles even in the normalized condition. Taking into account the absence of any consistent effect due to form and contentment of nitrogen in the welds, as well as the generally low notch toughness of the untreated oxyacetylene welds at all temperatures, we may conclude that other factors, perhaps porosity or grain size, had a much greater influence than nitrogen on Kleinefenn's results. It is interesting to speculate on what results would have been obtained if specimens had been quenched from normalizing temperature to the temperature of test in Kleinefenn's experiments.

Kleinefenn showed that quenching followed by aging for 12 days at 20° C. reduces the tensile ductility, and that notch-impact value at different temperatures is not sensitive to the different forms of nitrogen (nitrogen in solution and as nitride needles) present in the as-welded and normalized specimens. Both notch-impact value and tensile ductility were reduced by quench aging. Earlier, but less extensive tests by Hensel and Larsen[61] on the specimens listed in Table 25 and shown in Fig. 2, showed that as-welded specimens of high-nitrogen, high-oxygen weld-metal, which had considerable ductility as-welded, was embrittled after water quenching from 600° C. not only after holding 10 days at room temperature, but also immediately after quenching. The tensile strength of the as-quenched specimens was high but aging appeared to weaken one specimen, for no apparent reason. The low-nitrogen, low-oxygen weld metals (oxyacetylene and atomic hydrogen welds) were not embrittled by quenching or aging, although these treatments increased the tensile strength 25 to 75%.

The notch-impact value of Hensel and Larsen's specimens (no details of specimen) was 2.5 ft.-lb. or less for the bare electrode deposit in the three conditions listed in Fig. 2(*a*). The atomic hydrogen deposit had 68 to 79 ft.-lb. in all conditions but the oxyacetylene deposit, which had 38 ft.-lb. immediately after water quenching from 600° C., fell to 8.3 ft.-lb. after 10 days aging at room temperature.

The hardness of weld-metal containing 0.027 C, 0.004 Si, 0.006 Mn, 0.03 S, 0.016 P, 0.006 Al, 0.259 O_2, 0.127–0.147 N_2, deposited at 175 amps. by a bare electrode containing 0.02 C, is shown in Fig. 3. In Fig. 3(*a*) the hardness increase commencing at about 500° C. quenching temperature is related to the progressive solution of nitrogen. Reheating to different temperatures, Fig. 3(*b*) affects the hardness in a manner typical of a precipitation hardening alloy. Aging in ice (no details) gave the same results as aging at 25° C. The time-hardness curves, Fig. 3(*c*), are quite similar to those obtained by Kleinefenn. Maximum hardness is reached in 50 to 60 hr. at 25° C., but in much shorter periods at higher temperatures. A sample heated in hydrogen at 1000° C. for 96 hr. lost all capacity for aging. The nitrogen content, originally 0.142% was reduced to 0.030%. (In this connection Schuster[47] found that no visible nitrogen (chemical analyses were not made) appeared in the microstructure of a bare electrode weld-metal after being heated $3^1/_4$ days in hydrogen at 600 to 750° C. followed by normalizing at 910° C. Hodge,[76] however, showed that a weld-metal containing 0.13% nitrogen lost none as a result of heating in air 12 hr. at 600° C. or 8 hr. at 1000° C.) The loss in oxygen and carbon as a result of the treatment is not mentioned, but Hensel and Larsen were of the opinion that hardening due to oxygen is very slight and the carbon content was too low to cause hardening. Hensel and Larsen concluded that the increase in hardness and loss of ductility and toughness on aging are caused by the nitrogen content, which must be below approximately 0.05% to secure freedom from hardening.

In many respects, the results obtained by Hodge[76,85] confirm expectations. Like other investigators, with the exception of Kleinefenn, and Hensel and Larsen, Hodge did not analyze his weld-metals for oxygen, although it may be assumed that the oxygen contents reported by Kleinefenn apply, with reservations, to most weld-metals deposited by bare and covered elec-

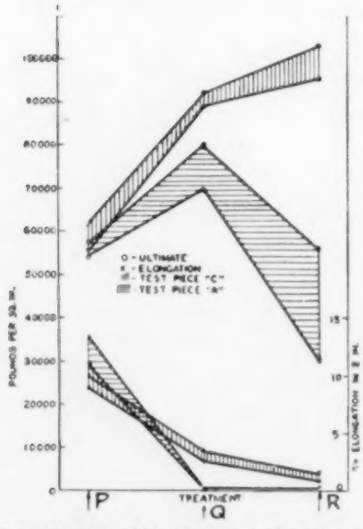

Fig. 2(*a*)—Effect of Heat Treatment on Strength and Elongation of Metal Arc Welds (Bare Electrodes)

Weld-metal "C" contained 0.028 C, 0.003 Si, 0.27 Mn, 0.035 S, 0.010 P, 0.003 Al, 0.183 O_2, 0.093–0.128 N_2; the bare electrode contained 0.29 C. See Fig. 3(*b*) for description of Weld-Metal "A"

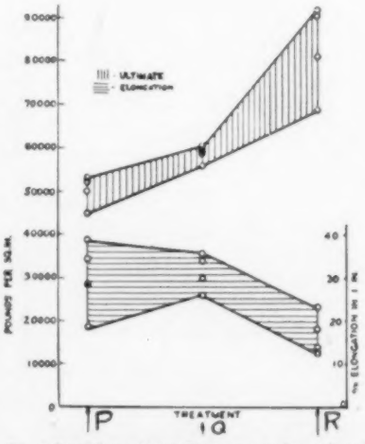

Fig. 2(*b*)—Effect of Heat Treatment on Strength and Elongation of Oxyacetylene Weld-Metal

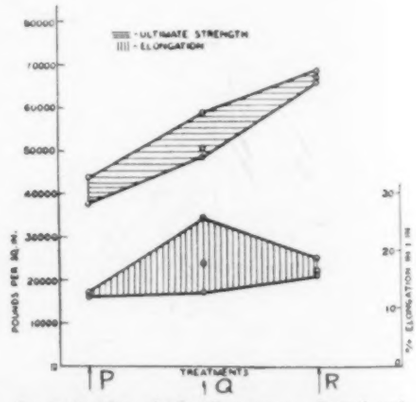

Fig. 2(*c*)—Effect of Heat Treatment on Strength and Elongation of Atomic Hydrogen Weld-Metal

P = as-welded
Q = Water-quenched from 600° C. and tested at once
R = Water-quenched from 600° C. and tested 10 days later. Hensel and Larsen[61]

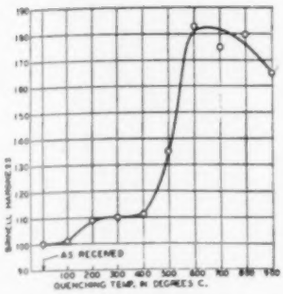

Fig. 3(a)—Effect of Different Quenching Temperatures on the Hardness of an Average Arc Weld (Bare Electrodes)

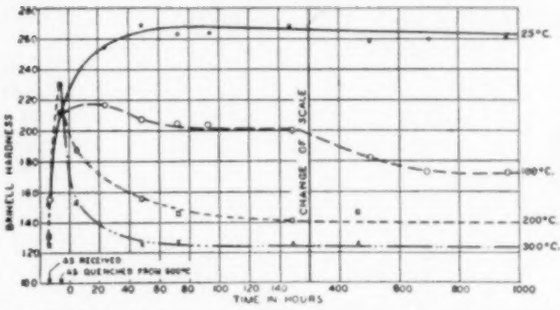

Fig. 3(b)—Effect of Different Reheating Temperatures on the Hardness of Bare Electrode Weld "A" After Quenching from 600° C. (1100° F.)

Weld-Metal "A" contained 0.027 C, 0.004 Si, 0.006 Mn, 0.03 S, 0.016 P, 0.006 Al, 0.259 O₂, 0.127–0.147 N₂; the bare electrode (175 amps.) contained 0.02 C

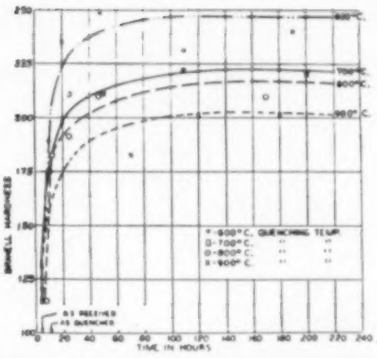

Fig. 3(c)—Hardness of Bare Electrode Weld-Metal "A" Quenched from Different Temperatures and Held (Aged) at Room Temperature Up to 10 Days. Hensel and Larsen[61]

trodes. Hodge realized that oxygen and other aging elements may influence the mechanical properties of welds but confined his attention to nitrogen.

Hodge determined the tensile and notch-impact properties of three weld-metals at temperatures from about 20 to 1040° C., Fig. 4. The Charpy impact value of a top run of the high-nitrogen weld-metal was less than 13 ft.-lb. at all temperatures, whereas the Charpy value of the covered electrode weld-metals was practically the same as ordinary steel at all temperatures. The bare electrode weld-metal is hot short, and both high- and medium-nitrogen weld-metal exhibit blue-brittleness phenomena at about 200° C., the severity of the blue-brittleness being approximately proportional to the nitrogen content. Sauveur twist tests on seven weld metals containing 0.02 to 0.11% nitrogen, 1 inch long, 0.250 inch diameter, at temperatures up to 500° C. showed that the angle of twist is higher for low-nitrogen than for high-nitrogen weld-metal. The high-nitrogen weld-metal showed a peak in torsional strength at 400° C., which was not observed in the low-nitrogen weld-metal and was an evidence of blue brittleness. On the basis of rotating-bend fatigue tests on welds made with bare and covered electrodes (no details) containing no defects, Hodge concluded that fatigue strength is independent of nitrogen content.

The hardness of Hodge's weld-metals after different treatments varied in a different way than the results of Hensel and Larsen would lead us to expect. In Fig. 5, which shows the quenching temperature-hardness relationship for bare and covered electrode welds previously annealed from above Ac 3 (time of test after quenching not stated), the bare electrode metal shows a hardness peak at 600° C., in agreement with Hensel and Larsen, but beyond 800° C. the hardness again rises. For all practical purposes the aging of weld-metal at room temperature is instantaneous (less than 2 hr.), Fig. 6, according to Hodge. Also, aging at elevated temperatures at 100° C. or above results in softening, Fig. 7. Again, the Rockwell hardness of single beads (90 B Rockwell) deposited by bare electrodes on a boiler plate 2 inches thick did not change during 42 days at room temperature. Hodge considered that in multi-layer deposits there would be even less likelihood of age

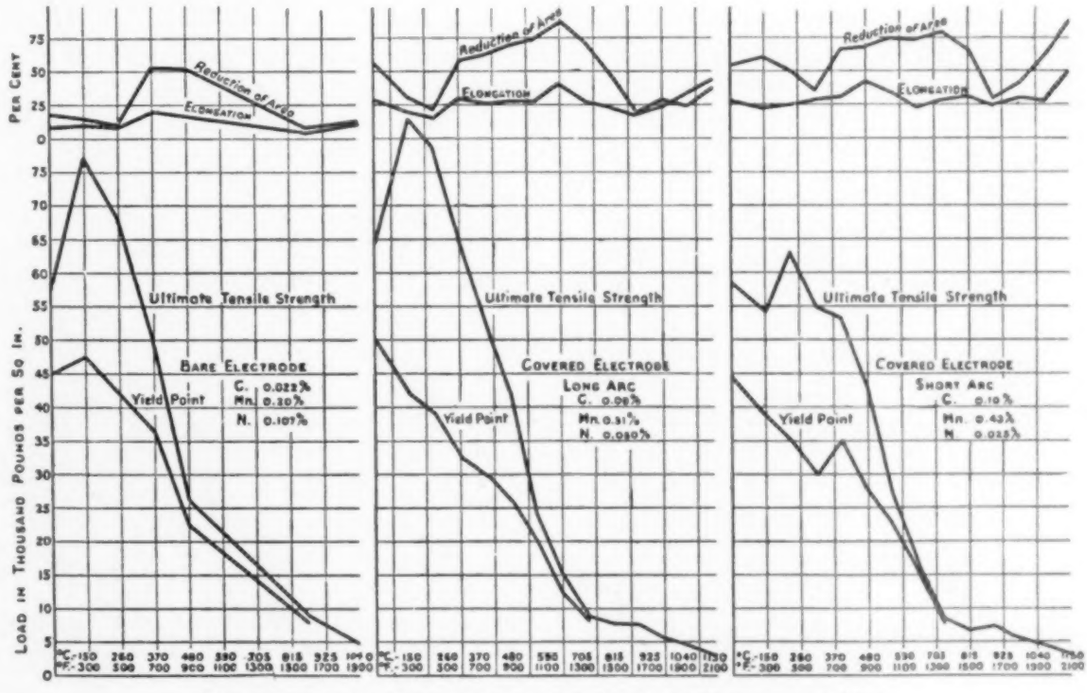

Fig. 4—Tensile Properties of Three Metal Arc Weld-Metals at Elevated Temperatures. Hodge[74]

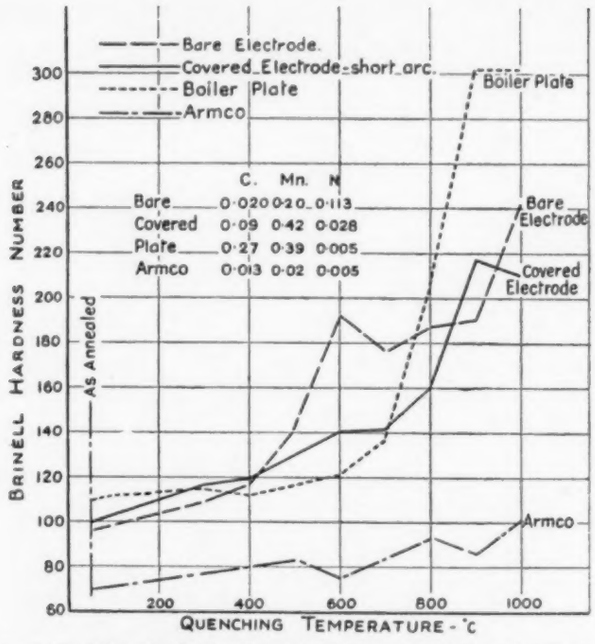

Fig. 5—The Relationship Between Quenching Temperature and Hardness for Specimens Previously Annealed Above Ac 3 Temperature. Hodge[76]

hardening. In the absence of complete information on the analysis of Hodge's weld-metal and on rates of cooling, it is not possible to reconcile the differences between Kleinefenn's and Hensel and Larsen's hardness results and those obtained by Hodge.

The static and impact tensile properties of two types of weld-metals were determined by Miller[35] using standard 0.505 inch static tensile specimens and impact tensile specimens have a parallel length of only 0.05 inch with a diameter of 0.312 inch. In the covered electrode type of weld metal (electrodes contained 0.015 to 1.00 C, 0.016 to 1.05 Mn, composition of weld metal not stated, with the exception of nitrogen content), which contained 0.022 to 0.043% nitrogen, the elongation in static tensile test was 20 to 38% in 2 inches, the reduction of area was 34 to 66% and the tensile impact value was 5 to 42 ft.-lb. The metal deposited by bare or lime coated electrodes (average nitrogen content 0.10%) had an elongation in static tensile test

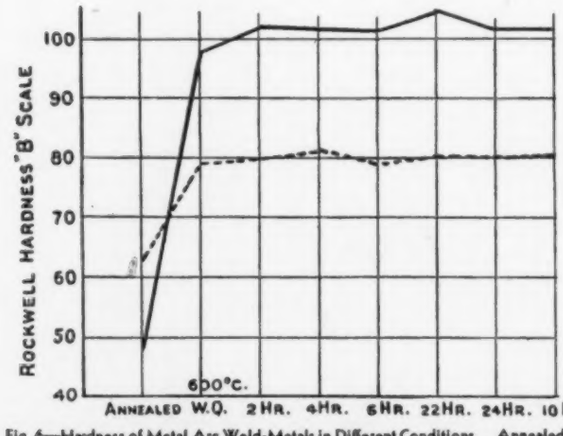

Fig. 6—Hardness of Metal Arc Weld-Metals in Different Conditions. Annealed Above Ac 3 Temperature, Water Quenched from 600° C. and Tested at Intervals Up to 10 Days at Room Temperature

Dotted line: Bare Electrode Weld-Metal (0.019 C, 0.18 Mn, 0.128 N_2). Full line: Covered Electrode Weld-Metal (0.09 C, 0.44 Mn, 0.025 N_2, short arc). Hodge[76]

of 4.5 to 14.5% in 2 inches, reduction of area 5.5 to 20.5% and tensile impact value 1 to 6 ft.-lb. All specimens were tested three weeks after welding to allow aging to have a maximum effect.

The static tensile and notch impact properties and hardness of eight weld-metals have been determined by Zeyen[63] in the as-welded, normalized and stress annealed conditions, Table 28. The welds were made in a 90° V. between two plates 0.79 inch thick containing 0.14 C, 0.11 Si, 0.54 Mn, 0.0018 N_2, using a welding rod 0.16 or 0.20 inch diameter containing 0.13 C, 0.07 Si, 0.66 Mn, 0.0050 N_2, 0.021 O_2. This rod was not the best for the purpose of oxyacetylene welding. The tensile specimens were 0.32 inch diameter, 1.9 inches parallel portion; the notch-impact specimen was of the standard German round-notch type (DVMR type). The length of the specimens coincided with the direction of welding. The hardness was measured with a ball 0.10 inch diameter, under a load of 187.5 kg. for 30 seconds. The welds consisted of about ten beads for oxyacetylene and twenty beads for metal arc. Only the topmost beads were analyzed, the hydrochloric acid solution process being used for nitrogen. The microstructure of the welds made with bare and light covered electrodes contained finely dispersed inclusions. Normalizing was at 900°

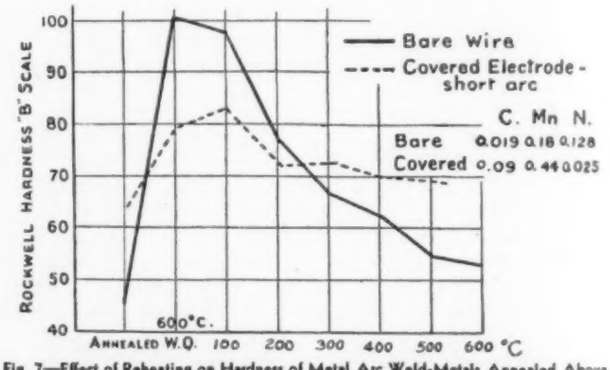
Bare Wire
Covered Electrode - short arc
C. Mn. N.
Bare 0.019 0.18 0.128
Covered 0.09 0.44 0.025
ROCKWELL HARDNESS "B" SCALE
600°C.
ANNEALED W.Q. 100 200 300 400 500 600 °C

Fig. 7—Effect of Reheating on Hardness of Metal Arc Weld-Metals Annealed Above Ac 3 Temperature and Water-Quenched from 600° C. Hodge[76]

C. (½ hr.) followed by air cooling. Stress annealing was at 600° C. (2 hr.) followed by air cooling. Rates of cooling and time elapsed between heat treatment and testing are not specified.

The combined effect of nitrogen content and porosity was considered by Zeyen to account for the results. Nitrides and finely dispersed inclusions and porosity caused the poor ductility, especially the low notch-impact value, of the welds made with bare and lightly coated electrodes. The only welds which heat treatment improved were those made by heavy covered electrodes; these welds also contained no nitride needles.

The tensile, fatigue and impact properties of welds made with five different electrodes in four plain-carbon and low-alloy steels were determined by Lohmann and Schulz,[6] who concluded that ductility and impact value were closely related to nitrogen content, but that rotating bend fatigue value and yield and tensile strength did not depend on nitrogen content. The analyses of some of the welds are given in Table 29. The welds were made in plates 0.47 and 0.79 inch thick, 60° V., the root being planed out to a depth greater than half the thickness. Tensile tests on specimens 0.63 inch diameter in the as-welded and the annealed (1 hr. at 920° C. for welds in plain-carbon steel; 1 hr. at 880° C. for welds in low-alloy steel) conditions showed very low ductility in all

Table 28—Mechanical Properties of Welds as a Function of Nitrogen Content and Heat Treatment. Zeyen[62]

	Heat Treatment	Composition of Weld C	Si	Mn	N	O	Tensile Test: Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 1.58 Inches	Reduction of Area %	Notch-Impact Value, Mkg./Cm.²	Brinell Hardness
Oxyacetylene Welded	*W*	0.10	0.02	0.49	0.017	0.037	36,100	56,600	18.5	38	11.8	113
	N						45,000	58,000	22.5	44	9.8	117
	A						38,200	53,800	23.5	41	12.9	108
Bare electrode, electrode negative, d.c.	*W*	0.03	0.02	0.20	0.14	0.210	43,700	59,400	7.5	17	1.5	135
	N						39,500	59,400	9.5	23	1.4	125
	A						39,500	56,600	7.5	14	1.9	119
Lightly coated electrode, electrode negative, d.c.	*W*	0.04	0.02	0.20	0.12	0.180	42,300	67,900	11.2	21	1.9	129
	N						38,300	63,700	13.5	23	1.5	125
	A						43,800	60,800	12.5	23	2.2	117
Lightly coated electrode, a.c.	*W*	0.05	0.03	0.21	0.12	——	45,100	66,500	12.0	21	1.7	133
	N						38,200	59,400	15.0	23	1.5	125
	A						40,900	59,400	12.5	23	1.6	121
Medium-heavy coated electrode, electrode positive, d.c.	*W*	0.04	0.04	0.25	0.079	0.140	43,700	62,200	15.0	30	6.1	131
	N						40,700	58,000	16.0	28	5.6	127
	A						39,500	58,000	16.0	27	5.7	119
Medium-heavy coated electrode, a.c.	*W*	0.04	0.03	0.22	0.085	——	42,400	59,400	15.0	28	5.1	138
	N						42,400	58,000	16.0	34	4.8	119
	A						33,800	55,200	16.5	34	5.1	111
Heavy coated electrode, shielded arc, electrode positive, d.c.	*W*	0.06	0.07	0.36	0.013	0.099	46,600	66,600	25.0	47	9.6	140
	N						46,600	65,900	26.0	49	9.9	131
	A						50,700	68,100	28.0	59	10.4	127
Heavy coated electrode, shielded arc, a.c.	*W*	0.08	0.08	0.41	0.028	——	49,500	70,500	26.5	40	8.6	148
	N						48,700	67,500	28.0	47	8.6	135
	A						54,000	70,500	31.0	62	9.8	125

W = as-welded
N = normalized, ½ hr., 900° C., air cooled
A = stress annealed, 2 hr., 600° C., air cooled

Table 29—Weld-Metals Tested by Lohmann and Schulz[6]

Electrode	Base Metal	C	Si	Mn	Cu	Cr	N_2
I cored	Mild steel; 0.08 C, 0.45 Mn	0.03	0.01	0.36	0.15	..	0.116
II bare	Same	0.03	0.08	0.22	0.79	0.25	0.123
III coated	Same	0.03	0.00	0.00	0.14	..	0.032
V covered	Same	0.08	0.16	0.59	0.08	..	0.005
I cored	Low-alloy steel; 0.18 C, 0.40 Si, 1.0 Mn, 0.75 Cu, 0.45 Cr	0.04	0.03	0.48	0.17	..	0.139
II bare		0.04	0.10	0.50	0.81	0.30	0.103
IV coated		0.09	0.07	0.74	0.18	..	0.006
V covered	Same	0.10	0.12	0.68	0.13	..	0.006

of the welds in low-alloy steels (about 5% elongation in 6 inches). The welds in plain-carbon steel, on the other hand had good ductility in the as-welded condition (about 18% elongation in 6 inches) and fair ductility after annealing. It is believed that some factors not mentioned by Lohmann and Schulz must have affected their results.

Tensile tests at temperatures from 20 to 600° C. on specimens 0.63 diameter with a parallel portion 0.78 inch long to force failure in the weld. The yield strength and tensile strength at all test temperatures were 90 to 100% of unwelded base metal. Unfortunately, ductility could not be determined on these specimens.

Nitrogen content was considered by Lohmann and Schulz to exert a powerful effect on notch-impact value. The notch-impact specimens were 0.39 x 0.39 x 2.4 inches, 1.58 inches between supports, with a notch 0.12 inch deep, 0.08 inch diameter, and were tested at temperatures from −80 to +200° C. Specimens with notch in the side of the weld had 20% lower notch-impact value than specimens with notch in the face of the weld. The results in Fig. 8, show that the high-nitrogen weld metals had low notch-impact value at all temperatures. Annealing was not advantageous for the high-nitrogen weld-metal. Artificial aging (10% compression followed by heating at 250° C. for ½ hr.) seriously lowered the notch-impact value of all welds, particularly at the lower temperatures. Nevertheless, Lohmann and Schulz

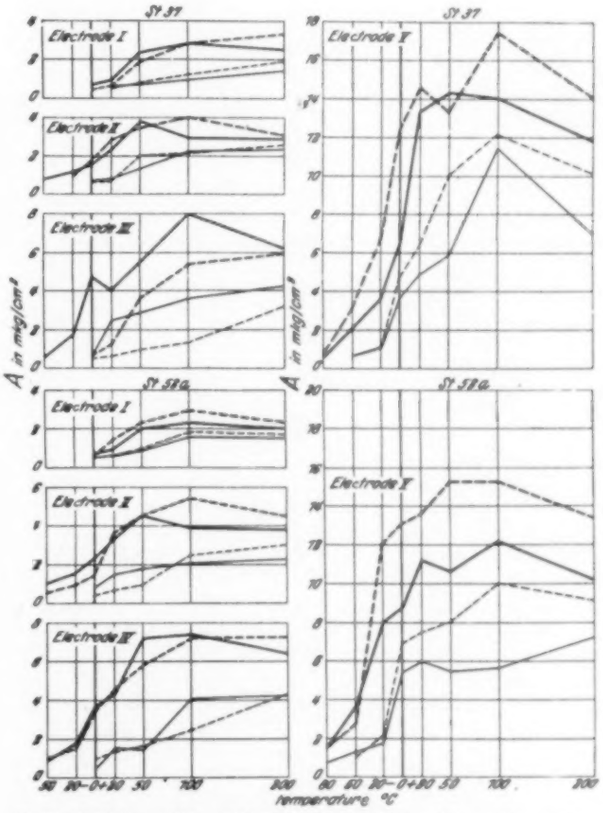

Fig. 8—Notch-Impact Value of Metal Arc Welds at Different Temperatures. See Table 29

Heavy Full Line = as-welded
Heavy Dotted Line = as-welded and annealed: 1 hr. at 880° C. for low-alloy steel, 1 hr. at 920° C for plain-carbon steel
Light Full Line = welded and artificially aged (10% compression followed by heating at 250° C. for ½ hr.
Light Dotted Line = welded, annealed and artificially aged
St 37 = plain-carbon steel
St 52(a) = low-alloy steel
A = notch-impact value. Lohmann and Schulz[6]

believed that the effect of artificial aging was about proportional to nitrogen content, and that cold peening of the top layer of a weld induces nitrogen brittleness.

Even more striking than the notch impact results were the results obtained on unnotched specimens of the welds in plain-carbon steel, Fig. 9. The specimens were 0.79 x 0.79 x 6.3 inches, 4.7 inches between supports. The blow was struck perpendicular to the weld. Welds with medium and high contents of nitrogen showed a decided decrease in unnotched impact value at low temperatures. The low-nitrogen welds retained good unnotched impact value even at −80° C. Annealing 1 hr. at 920° C. had little effect on the unnotched specimens. Repeated impact tests (no details) were made on specimens 0.59 inch diameter with a notch 0.04 inch deep, 0.32 inch radius. There was no relation between the number of blows withstood and the nitrogen content, although annealing above A_3 decreased the repeated impact value of the high-nitrogen welds by 25 to 50%.

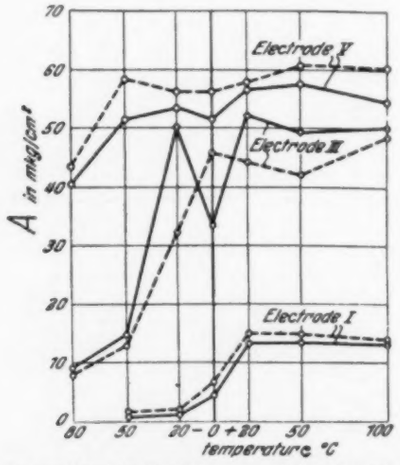

Fig. 9—Impact Tests on Unnotched Weld Specimens of Plain Carbon Steel at Different Temperatures. See Table 29

Full Line = as-welded
Dotted Line = welded and annealed at 920° C. for 1 hr.
A = impact value. Lohmann and Schulz[4]

Although it is obvious that high-nitrogen content (above about 0.03–0.05%) has a bad effect on the notch impact value of weld metal, it is difficult to conclude which form of nitrogen has the most serious effect. According to Leitner and Schmidt,[27] the needle form of nitrogen has the least effect on brittleness, but grain size was found to be a far more important influence than nitrogen on oxyacetylene welds in mild steel. Although the welds contained only about 0.020% nitrogen and a similar amount of oxygen, needles were plentiful. Untreated oxyacetylene welds (German standard round notch specimen) had an impact value of about 2 mkg./cm.², welds heated to 600° C. and slowly cooled had 3 to 9 mkg./cm.², and normalizing at 940° C. refined the grain size and raised the notch-impact value to 13–14 mkg./cm.².

Whereas Leitner and Schmidt did not consider notch-impact value to depend on nitrogen, Quadflieg[78] believed that a structure containing needles has the best impact value. Of the specimens listed in Table 30, Specimen 1 contained no needles, on account of the chilling action of base metal; specimens 2 and 3 had about the same grain size as specimen 1, but 2 contained globular nitride whereas 3 contained needles; specimen 4 had a very fine grain size without visible nitrides, although the cooling from 630° C. was in calm air. Notch impact tests (German standard round notch specimen) on arc weld-metal containing 0.09 C, 0.48 Mn, 0.18 Si, 0.05 S, 0.043 P, 0.032 N_2, 0.109 O_2 at temperatures from −80 to +500° C., Table 30, showed that, as a matter of fact, there is not a great difference between specimens 2 and 3, and that Quadflieg's belief in the beneficial effect of needles is not well founded. Strokopytov[57] observed that the appearance of nitride needles in heat treated arc welds in mild steel coincided with low notch-impact value.

Table 30—Notch-Impact Value of Low-Nitrogen Weld-Metal (Mkg./Cm.²) Quadflieg[78]

Specimen	(Time elapsed between heat treating and testing not stated) −50° C.	−20° C.	0° C.	+20° C.	+150° C.	+500° C.
1. As-welded	0.9	2.0	3.5	5.5	5	4.5
2. Heated at 850° C., slowly cooled	0.2	0.8	2.5	6	9.5	4
3. Heated at 850° C., rapidly cooled	0.4	0.8	1.5	7	10.5	4
4. Water quenched from about 900° C., reheated to 630° C., slowly cooled.	0.9	5.0	6.5	7.5	7.5	4

An attempt to correlate notch impact behavior of plain-carbon weld-metal with the form of the nitrogen, Table 31, was made by Schuster,[47] who used a deposit made by a bare electrode (nitrogen content not stated). The results show that braunite probably contributes to the brittleness of high-nitrogen weld-metal and that the martensite formed in the high-nitrogen weld-metal is brittle.

Table 31—Correlation Between Notch-Impact Value and Microstructure of a Weld Deposited by Bare Electrodes. Schuster[47]

Specimen	Izod Impact Value, Ft.-Lb.	Brinell Hardness	Microstructure
As-welded	1.0–1.5	117.5	Widmannstätten
Heated to 910° C., cooled slowly in air	1.2	96.7	Braunite + needles
Heated to 910° C., cooled quickly in air	2.0–3.0	98.0	Needles
Heated to 910° C. water-quenched	1.2–1.4	180	Completely martensitic
Heated between 600 and 750° C. for 3¼ days in hydrogen to reduce the nitrogen content, normalized at 910° C. 4 days later	7.0–8.0	73	No needles and no braunite
Heated between 600 and 750° C. for 3¼ days in hydrogen to reduce the nitrogen content, normalized at 1000° C. 4 days later	9.0–11.0	...	No needles and no braunite but smaller grain size

The conclusions to be drawn from available information on the mechanical properties of welds of mild steel grade containing nitrogen are:

1. High-nitrogen (and high-oxygen) weld-metal (above about 0.03–0.05 N_2) in the untreated condition lacks the customary ductility of mild steel in the static tensile test at temperatures from 20 to 1000° C. The notch-impact value of high-nitrogen welds in mild steel is very poor (1 to 10 ft.-lb.). Low-nitrogen welds have impact values of 40 ft.-lb. or more (approximately the same as unwelded steel).

2. Water quenching from 600° C. or above, with or without aging (holding for a period of time) at room temperature, as well as artificial aging (about 10% strain at 20° C. followed by heating at 250° C.) seriously lower the ductility and notch toughness if the nitrogen content of the weld-metal exceeds about 0.04%.

3. Air cooling or furnace cooling from 600° C. or

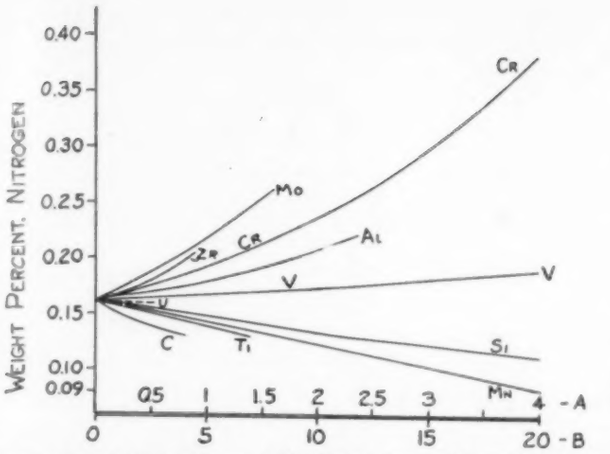

Fig. 10—Effect of Alloying Elements Added Singly to Iron and Nitrogen Pick Up in Welding with a Bare Iron or Iron Alloy Electrode in Air. Portevin and Séférian[42]

Upper Scale = *A*: weight per cent carbon (C), Manganese (Mn), Silicon (Si), Zirconium (Zr), Vanadium (V), or Uranium (U) in the bare electrode

Lower Scale = *B*: weight per cent Aluminum (Al), Chromium (Cr), or Molybdenum (Mo) in the bare electrode

above as an adverse effect on notch value in plain carbon welds although it may improve the static ductility. Such heat treatment appears to improve welds made with nickel steel rods.

4. High-nitrogen welds containing 2% nickel appear to have low notch toughness and static ductility but not to so great an extent as unalloyed deposits nor are they as dangerously sensitive to water quenching.

5. Ductility and notch toughness can be imparted to high-nitrogen weld-metal only by removing the nitrogen, for example, by heating several days in hydrogen at 600 to 1000° C.

6. Welds with medium and high nitrogen show a decided decrease in unnotched-impact values at low temperature. The low-nitrogen welds on the other hand, retain good unnotched-impact values even at −80° C.

7. Slight effects due to nitrogen appear to be produced in welds containing as little as 0.018% nitrogen.

8. Of the different microstructures appearing in high-nitrogen weld-metal, the needle structure appears to be more ductile than the martensitic (water-quenched from above about 700° C.) and the supersaturated solid solution (water-quenched from 550–600° C.).

9. Proof is lacking that the poor mechanical properties of bare electrode weld-metal are due to nitrogen alone or primarily. Other impurities and grain size exert powerful influences on the mechanical properties.

10. The welding of mild steel plate containing 0.03 C, 0.020 N may create a zone of lower strength than base metal in the region heated to 320° C. maximum during welding.

ACKNOWLEDGMENTS

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SUGGESTED RESEARCH PROBLEMS

1. Nitrogen pick up in controlled atmospheres.
2. Which of the constituents of coatings are most effective in reducing nitrogen pick up?
3. Solubility of nitrogen in iron up to the boiling point of iron.
4. The effect of the size of the weld puddle and rate of solidification on nitrogen pick up.
5. Does a bead of covered electrode weld-metal absorb nitrogen when deposited on an iron-nitrogen alloy, such as a bare electrode deposit?
6. Distinction between the aging effects exerted by carbon, oxygen and nitrogen in low-carbon steel weld-metal deposited by bare electrodes and having different contents of the three elements.

THE FAILURE OF GIRDERS Under Repeated Stresses

By PROF. FREDERICK CHARLES LEA and JOHN GWYNNE WHITMAN

FATIGUE-TESTS ON MILD-STEEL GIRDERS

THE girders chosen for the tests were all of a broad-flange type and all failed in the tension-flange, no buckling occurring in the compression-flange. The girders were 5 inches by $2^1/_2$ inches by 9 lb., and were stamped M.S. 1, M.S. 2, etc.

The testing machine consisted of a motor-driven eccentric the motion of which was delivered in such a way to an auxiliary girder that the motion of the latter was in a vertical plane. The motion of the auxiliary girder was transmitted directly to the test girder by two links 12 inches apart. The ends of the test girder were supported on bolts inserted in holes in the center of the web. The bolts transmitted the load to a 10-inch beam, which formed the bed of the testing machine. The speed of testing was 320 cycles per minute. The amplitude of motion of the test girder was measured at testing speed by means of micrometer contacts. A steel ring with dial gage was used for calibrating the machine. The accuracy of the tests was estimated to be 2 to $2^1/_2\%$; that is, 550 to 1100 lb./in.^{2} in a range of stress of 33,600 lb./in.^{2}

The results of the tests are shown in Fig. 1, from which the fatigue-limit for 10^7 repetitions of stress, from a minimum stress of zero, is seen to be 33,000 lb./in.^{2}

FATIGUE-TESTS ON BUTT-WELDED MILD-STEEL JOISTS

The joists, 5 inches by $2^1/_2$ inches by 9 lb., were supplied in 8-foot lengths. These were cut through the center and the two half-girders were butt-welded together as shown in Fig 2. The weld-metal was machined level with the surface of the flanges, but that under the flange and on the web was left as received. Gages 10 and 12 of a well-known electrode were used to make the welds, which were made in the works. Specimens were machined from the compression-flanges of girders M.S. 11 and M.S. 13, so as to include the weld. The specimen from M.S. 11 was machined to $^1/_2$ inch diameter. The surface of the specimen was well below the scale.

Abstracts from a paper published in the *Journal of the Institution of Civil Engineers*, Paper No. 5080, (No. 1, 1937–1938, pp. 119–146). Professor Lea is head of the Faculty of Mechanical Engineering, University of Sheffield, England.

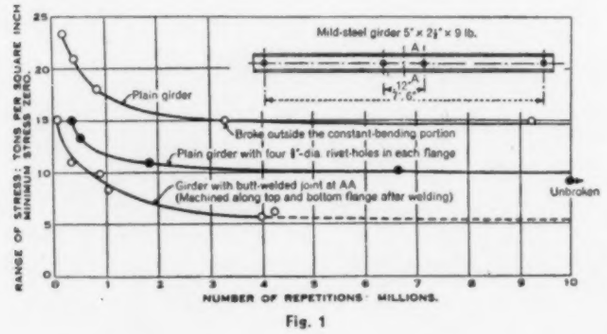
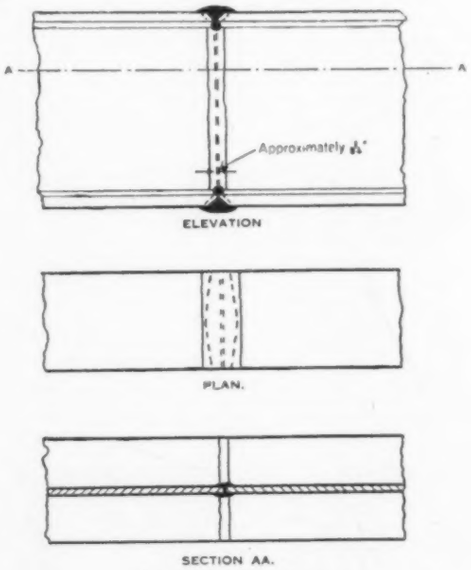

Mild-steel girder 5" × 2½" × 9 lb.
A
A
12"
7' 6"
Plain girder
Broke outside the constant-bending portion
Plain girder with four ⅜"-dia. rivet-holes in each flange
Girder with butt-welded joint at AA
(Machined along top and bottom flange after welding)
Unbroken
RANGE OF STRESS: TONS PER SQUARE INCH
MINIMUM STRESS ZERO.
NUMBER OF REPETITIONS · MILLIONS.

Fig. 1



BUTT-WELDED JOINT.

Fig. 2

The results of a tensile test of a $^1/_2$-inch diameter specimen were:

Yield-point: 11.5 tons* per square inch.
Ultimate strength: 20.8 tons per square inch.
Total extension on length of 2 inches (including weld): approximately 5 per cent.

The specimen taken from the girder M.S. 13 was machined until all traces of the "lack of penetration" had been removed. The diameter was $^1/_4$ inch.

The results of a tensile test of a $^1/_4$-inch diameter specimen were:

*Long-ton = 2240 lb.

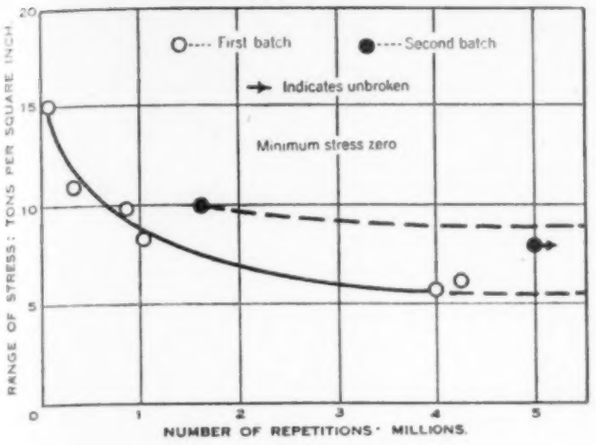


Fig. 3

Yield-point: 18.3 tons per square inch.
Ultimate strength: 29.3 tons per square inch.
Total extension on length of 2 inches (including weld): approximately 9.5 per cent.
Both specimens broke through the center of the weld.

The results of the repeated-stress tests of the welded joists (Table 1 and Figs. 1 and 3) are startlingly low. A crack in one of the girders started near to the center of the weld in the tension-flange and proceeded partly in the weld-metal and partly in the plate. Near the top of the web there was evidently very poor fusion of the weld-metal and the flange. It may be that the crack commenced here. It has already been stated that these welds were made of a well-known electrode and in a works by an experienced welder. They are given here not as an example of the best that can be done by welding but rather as an example of what is to be avoided. A very large number of tests in this and other machines has shown that under repeated stresses the greatest danger is lack of penetration. Other tests are in hand.

Table 1—Fatigue-Tests of Welded Joists

Girder	Moment of Inertia of Section of Girder: Inch⁴ Units	Range of Stress: Tons per Square Inch	Repetitions	Remarks
M.S. 11	11.27	15.1	66,000	Broken
M.S. 13	11.36	11.0	310,000	Broken
M.S. 14	10.72	9.9	878,000	Broken
M.S. 15	10.68	8.4	1,022,000	Broken
M.S. 16	10.81	6.2	4,209,000	Broken*
M.S. 12	11.07	5.7	3,981,000	Broken

* The cut-out stopped the machine when the only sign of a fracture was an extremely fine line on the surface of the weld which did not open out at the top of the stroke; 4 hours after restarting, the girder had cracked half-way through.

Fatigue-limit from zero minimum stress for more than 4×10^6 repetitions = 5.5 tons per square inch.

It seems only possible to account for the very low fatigue-range obtained from these girders by assuming that the fatigue-crack commenced in the neighborhood of the area just above the top of the web, where there was a definite discontinuity and where the direct stress was not very much less than the direct stress at the outer boundary.

The tests of the joists, of which particulars are given in Fig. 3, having given disappointingly low results, a further series was prepared by another expert welder, care being taken to insure that there was penetration at the bottom of the V. The results of the tests of these joists are also shown on Fig. 3. One specimen broke after 1,500,000 repetitions at a stress of 10 tons per square inch. The fatigue-limit from zero minimum stress for more than 5×10^6 repetitions is approximately 9 tons per square inch. The point W in Fig. 4 indicates the fatigue-range for these joists. Thus, by care in welding the range has been increased from $5^1/_2$ to 9 tons per square inch; this is slightly better than the worst result obtained from certain riveted joints tested in tension.[1]

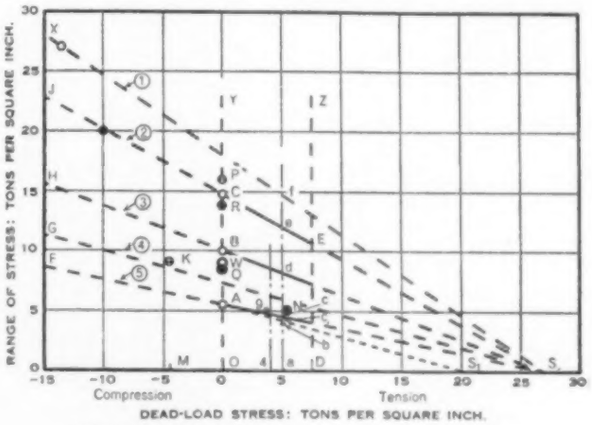
One of the authors has carried out, on a specially-designed machine, a large number of tests of butt-welds,[2] which have given fatigue-ranges at zero mean stress of more than 75 per cent of the fatigue-range of plates of the same tensile strength. Some specimens failed in the plate and not in the weld. Others, however, have given fatigue-ranges less than 50 per cent of that of the plate.

FUTURE WORK

Girders with riveted joints, with various forms of welded joints and welded girders built up from plates, are being made for tests. It is also hoped to test butt-welds in 3-inch plates, similar to those proposed for high-pressure boiler-drums.

RESULTS OF THE TESTS, AND THE FACTOR OF SAFETY

From the results of these tests, together with many others carried out by one of the authors on welded plates, it is possible to give a simple diagram from which, assuming certain dead-load stresses in a girder and certain repeated-stress loadings, due to travelling loads and vibrations (these are particularly important in railway structures over which steam locomotives pass[3]), the safe repeated load that can be impressed upon a dead load can approximately be determined. The minimum stress to which the girder is to be subjected should be plotted as abscissas, Fig. 4 and the range of stress as ordinates. In the tests described the minimum stress was zero. Then OA, OB and OC are the safe ranges of stress for zero minimum stress for the welded mild-steel girder, the drilled girder and the undrilled girder, respectively. From these points straight lines should



SAFE RANGES OF STRESS FOR VARIABLE MINIMUM STRESS.

① Turned mild-steel specimens
② Rolled-steel joists and some welds
③ Rolled-steel joists with holes in the tension-flange
④ Rather indifferent welds
⑤ Butt-welded joists examination of which after fracture showed obvious defects

Fig. 4

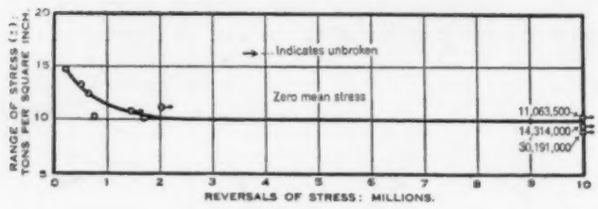


Fig. 5

be drawn to a point of minimum stress equal to the breaking strength of the plates. This was about 27 tons per square inch. The strength of the weld-metal varied from 20 to 29.5 tons per square inch, but the former value was from a bad specimen. Through the points *A*, *B* and *C*, straight lines are drawn to the point *S* and produced to *F*, *H* and *J*. Then the safe range of stress for a very large number of repetitions of stress is given approximately by *JS* for the undrilled girder, *HS* for the girder with holes in the flanges, and *FS* for the rather bad batch of welded joists. For actual cases only a short length of these lines applies, say, between *OY* and *DZ*, and only a small difference is made by changing the forms of the curves *CS*, *BS* and *AS*. If the curve is assumed to be AS_1 for the welded joint, the difference of *AS* and AS_1 between *YO* and *ZD* is not very marked. Let now *Oa* be any dead-load stress and *ab* the range of stress produced by traveling loads. Then the factor of safety for the girder with rivet-holes may be said to be approximately $\frac{ad}{ab}$ and for the badly-welded girder $\frac{ac}{ab}$ or $\frac{ac_1}{ab}$. The maximum stress in the girder is $oa + ab = 9$ tons per square inch. If the dead-load stress is 4 tons per square inch and the maximum stress is 9 tons per square inch, the factor of safety of this particular welded girder for 4×10^6 repetitions of stress is less than unity. Point *K* shows an experimental point from butt-welds, and *SG* shows a probable line for butt-welds of certain plates tested by one of the authors. He has also obtained[4] values approximately corresponding to the line *SJ*, and in some cases points lying well above *SJ*. Figure 5 shows results at zero mean stress from turned specimens of weld-metal having the composition:

Carbon	0.10	per cent
Manganese	0.53	" "
Sulphur	0.025	" "
Phosphorus	0.11	" "
Silicon	Trace	

The weld-metal was laid down from electrodes on to a flat steel plate, into ingots approximately 12 inches by $1\frac{1}{2}$ inch by $1\frac{1}{4}$ inch. From these ingots test-specimens 0.25 inch in diameter were prepared and tested in a "constant-bending-moment" machine.[5] The results of the tests are shown in Fig. 5, and *SJ* (Fig. 4) shows a probable safe-range line for various minimum stresses for machined specimens of this weld-metal. *SX* shows approximately the safe-range line for mild-steel turned specimens having a tensile strength of 27 tons per square inch. Point *N* corresponds to results of tests on welded joints carried out by Dr.-Ing. H. E. Neese.[6] Points *P* and *K* are two examples of points obtained by one of the authors from welded joints tested under bending cycles of stress.[7] Points *Q* and *R* were obtained from tests of riveted joints, stressed in tension only from zero minimum stress. In the experiments now in hand various types of riveted and welded joints will be compared, and it is hoped to be able to prepare welded joints that will be better able to resist repeated stresses than riveted joints.

CONCLUSIONS, AND THE MEANING OF THE FACTOR OF SAFETY

The results given in this preliminary paper show that the static tests of materials and structural elements are by no means a safe guide to indicate the ranges of stress to which materials can be subjected, when the stresses are repeated. For example, a rolled-steel joist that is drilled and strengthened by the addition of plates to the tension-flange will be stiffened against deflection, but may be weaker under repeated stresses. Welded joints in mild-steel plates can be made that will withstand repeated stresses as great as those that a black rolled mild-steel joist will withstand, but, as shown in the paper, unless great care is taken with the welding, fatigue-ranges of the order of one-third of those resisted by the joist may be obtained from welded joints. Unless designers of welded joists that are to be subjected to repeated stresses carefully control both the design and the technique of making the joint, only low fatigue-ranges can be relied upon. If, however, the fatigue-range is kept below the line *FS* in Fig. 4 for specified minimum stresses, many millions of repetitions can be relied upon without risk of fracture. From Fig. 4, it is possible to give some specific meaning to the "factor of safety." If a mild steel is bright turned, then for a dead-load stress of 5 tons per square inch and a range of stress of 4 tons per square inch above the 5 tons per square inch, the factor of safety would be $\frac{af}{ab}$. A drilled flange of a girder may have a factor of safety $\frac{ad}{ab}$. For a welded joint, a good portion of the joint of which will have the same tensile strength as the mild steel, the factor of safety may be anything between $\frac{ae}{ab}$ and $\frac{ac}{ab}$ unless the technique and the design of the joint are carefully controlled.

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participate. Several of the steel and fabricating companies are supplying specimens. Additional funds are being solicited to continue the program on a three-year basis.

Fundamentals of Resistance Welding

An extensive program on the Fundamentals of Resistance Welding has been initiated at Rensselaer Polytechnic Institute through the establishment of a research fellowship by the Committee commencing January 1, 1938. The first work will be devoted to a critical digest of the literature. A preliminary program was published in the March Research Supplement.